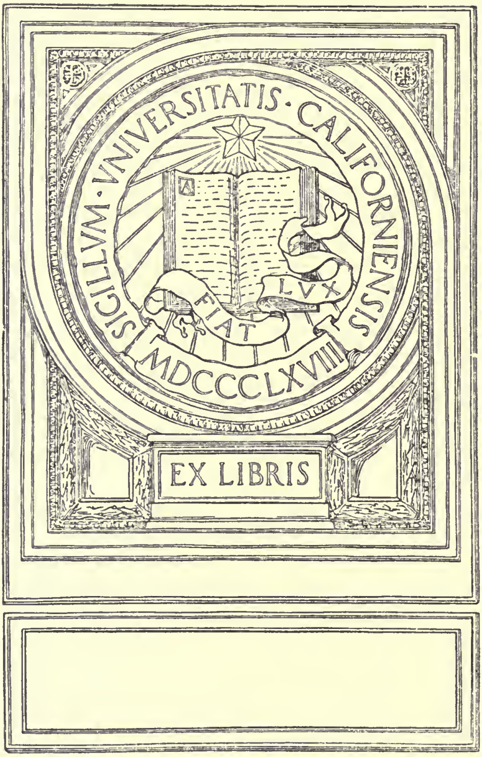
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High-Efficiency Electrical Illuminants and Illumination

By

Rollin W. Hutchinson, Jr.

FIRST EDITION

FIRST THOUSAND

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TO J. ROBERT CROUSE,

INDEFATIGABLE PROMOTER AND ZEALOUS ADVOCATE OF HIGH-EFFICENCY ELECTRICAL ILLUMINATION, TO WHOM THE CENTRAL STATION AND ILLUMINATING ENGINEERING FRATERNITY OWE MUCH, THIS VOLUME IS DEDICATED WITH THE HIGHEST RESPECT AND ADMIRATION OF

THE AUTHOR

PREFACE

For nearly twenty years after the historical lighting of Menlo Park, New Jersey, in 1879, with Mr. Edison's carbonized bamboo filament incandescent lamps, the improvements in both incandescent and arc types of electric light sources consisted more in the perfection of details than in the evolution of lamps of higher efficiencies. The low efficiencies of existing electric light sources was the continual deprecation of the technical press. True, the appearance of "metallized" carbon lamps in the early years of the present century marked a new era in incandescent lighting, yet as serviceable and economical as such lamps are, they are very inefficient as compared with the class of lamps of which they are the progenitors—the metal-filament lamps.

Following the announcement of Bremer's flaming-arc lamp in 1899, came the startling advice (1903) that incandescent lamps employing filaments of the metal tantalum, exhibited the remarkable efficiency of two watts per candle-power, and gave illumination approaching daylight in color value. Hardly had this announcement appeared before the illuminating engineering world was again aroused from its accustomed indifference and cynicism by the almost incredible news that the rare metal tungsten (wolfram) could be employed as the resisting medium in

vacuum lamps, and produce an efficiency of a small fraction over one watt per candle-power, and that with a color value nearer like daylight than any other illuminant.

Since the commercialization of the metallic filament, flaming and luminous arc lamps, the electric lighting industry, within the past three years, has been revolutionized; and central stations are still adjusting themselves to the new conditions imposed by the modern high-efficiency illuminants.

The author has been induced to prepare this little volume by the constant demand of layman and engineer alike, for information on the principles of the new light sources, their manufacture, use, care, and handling. The volume is necessarily largely didactic, and in preparing it the aim has been to make it intelligible to the serious general reader as well as useful as a reference to the central station man of progressive ideas. The book does not claim to be exhaustive, nor does it purport to more than generalize on the proper use of the new illuminants for various conditions of lighting, interior and exterior.

Much of the material for the work has been gathered from the pages of such leading periodicals as *The Electrical World* (especially), *The Illuminating Engineer, London Electrician, La Lumière Electrique,* and *Electrotechnische Zeitschrift.*

The author is most grateful to the manufacturers of the lamps and reflectors herein discussed for cooperation in supplying illustrations and data on their appliances.

PITTSBURG, SEPTEMBER, 1910.

TABLE OF CONTENTS

PAGE

CHAPTER I

Light and Color 1

CHAPTER II

Photometry—Units of Illumination 8

CHAPTER III

Metallic Filament and Electrolytic Incandescent Lamps 16

CHAPTER IV

Arc Lamps 114

CHAPTER V

Vapor Lamps 166

CHAPTER VI

Fundamental Principles Involved in Efficient and Economical Interior Illumination 188

CHAPTER VII

Notes on Street Illumination 248

High Efficiency Electrical Illuminants and Illumination

CHAPTER I

LIGHT AND COLOR

Light, heat, electricity, and, in fact, all forms of energy have inherently the same origin: viz., vibratory or wave motion in the ether, which is the medium permeating all space and all matter. According to the rate of vibration of ether waves there are developed the various phenomena which we call sound, light, heat, and electricity.

Waves in the ether which oscillate at the slowest velocity produce sound. The human ear is capable of hearing sound waves of not less than 16 nor more than 44,000 per second.

It is estimated that the sun is sending out light waves whose rate of motion is over five hundred trillion oscillations per second.

When one sees a coal glowing at a red heat or anything at that temperature it is sending out waves at the rate of forty billions per second.

The waves in the ether which produce electricity have been calculated to move at the prodigious velocity of eight hundred trillions of vibrations per second. The human mind is too feeble and the eye too crude to register an impression of the motions or oscillations.

Waves of light striking against a surface are either reflected, absorbed, or transmitted, depending on the character of the surface, the substance of which it is composed, and the physical properties of the surface. On a smooth surface the waves are reflected, are of specular nature, and make an angle with a normal equal to the "angle of incidence." On a rough surface waves of light are diffused. The phenomenon which we term color is due both to the kind of substance and the arrangement of its molecules, which cause rays of a desired frequency to be either reflected or transmitted. The wide difference which substances possess in their property of absorption and reflection causes the variation in colors of objects.

The table below (the arrangement of which is due to Professor Barrows) gives the amount of light reflected from surfaces of different colors in per cents of the light received:

Nature of Surface	Per Cent Reflected	Nature of Surface	Per Cent Reflected
Mirror	95	Plain deal (dirty)	20
Polished silver	90	Yellow paint (dirty)	20
White paper	80	Emerald green paper	18
Silvered glass	80	Dark brown paper	13
Polished brass	70	Vermilion paper	12
Chrome yellow	60	Blue-green paper	12
Orange paper	50	Cobalt blue paper	12
Plain deal (clean)	45	Macadam road	12
Yellow paper	40	Glossy black paper	5
Yellow paint (clean)	40	Ultramarine blue paper	4
Light pink paper	35	Deep chocolate paper	4
Tracing cloth	30	Lead black surface	1
Blue wall-paper	25		

Mechanism of the Eye.—The organ of sight is made up of three essential parts termed the iris, the focussing lens, and

the retina. The iris is a diaphragm which expands or contracts to regulate within certain limits the amount of light which passes through the focussing lens and strikes the retina at the back of the eyeball, thereby exciting the optic nerves which lead to the base of the brain. The nerves in the retina are termed the "rods" and the "cones." Of these three parts of the eye the retina is the most sensitive. Its recuperative power, however, is marvellous despite its delicacy.

The cones of the eye display the most activity at ordinary values of illumination, being most susceptible to yellow light. Decrease of illumination causes the rods to become the predominating members, and blue and green become the most serviceable colors of the spectrum.

Thus at very weak illuminations only the rods are in action. We find difficulty in distinguishing colors properly and all objects appear a "ghostly" gray. Increase of illumination causes the cones suddenly to begin to act. Colors appear and a struggle for predominance between the rods and cones takes place. This struggle is supposed to account in the main for the "Purkinje effect" (first observed by a scientist of this name). By the Purkinje effect is meant that with increasing stimulus the luminous sensation produced by the red end of the spectrum increases more rapidly than in the case of the green end. The effect is due merely to a partial physiological change in the eye which occurs at low illuminations and is commonly illustrated by the following simple experiment. Two similar pieces of green and red paper are illuminated with white light from some convenient source. The red will then in general appear the brighter of the two when the illumination is strong. Decrease of illumination causes the red to darken more rapidly than the green, which soon

appears unmistakably the brighter of the two. After this stage the colors begin to fade, and in time the green appears white and the red becomes jet black. The green will also fade away into darkness on still further decreasing the illumination. Satisfactory results with this experiment require that the colored surfaces subtend a considerable angle at the eye. If the angle is very small the colors fade away together and the Purkinje effect does not appear.

The proper arrangement of luminous sources requires that the rays, either direct or reflected, do not pass directly into the eye. If this precaution is not heeded the result is that objects back of the source, in the case of direct rays, and of the reflecting medium—if the rays are reflected—are indistinct. Light emanating from an unusual angle should be avoided as should also streaks of light and sharp contrasts, which are very injurious to the eye, being equivalent in effect to a flickering light.

Tests and experience demonstrate that illuminations of from one to two foot-candles result in the eye working under such normal conditions that further increase of illumination has but little effect. It should be understood that these values refer to those affecting the eye and not to those which illuminate the objects.

Color Values of Various Sources of Light.—The selection of the proper illuminant to obtain true color values is a very important thing in interior lighting—particularly so in stores or shops where colored articles are sold, requiring illumination which produces color values nearly equivalent to diffused sunlight.

The following alphabetical arrangement of the color of various natural and artificial sources of light is given as

a preliminary to the discussion of their value for different kinds of illumination:

Acetylene	Nearly white.
Arc light (enclosed)	Bluish white to violet.
Arc light (open)	White.
Arc light (high voltage arc)	Purple.
Candle	Orange yellow.
Carbon-filament (under voltage)	Orange to orange red.
Carbon-filament (normal voltage)	Yellowish white.
Flaming arc	Yellowish orange, pearl white or pale pink, depending on carbons
Gas light (open flame)	Pale orange to yellowish white.
Metallized filament	Nearly white, slight yellow.
Kerosene lamp	Orange, slightly yellow.
Nernst lamp	Very nearly white.
Sky light	Bluish white
Sun (high in sky)	White.
Sun (near the horizon)	Orange red.
Tantalum lamp	Nearly white.
Tungsten lamp	Very nearly white.
Magnetite arc lamp	Bluish white.
Mercury lamp	Bluish green
Moore lamp	Yellow, white or pink.
Welsbach mantle	Greenish white.

The color of incandescent lamps varies widely with the degree of incandescence. Operated at low voltage or when the filament has greatly exceeded its useful life, the light they emit is nearly similar in color to gas light. If operated at excessively high voltages with consequent increase of candle-power their spectrum is full of violet rays; on further increase of pressure they soon assume a vivid white and quickly burn out.

Colorimeter Measurements of Various Sources of Light.—Mr. Frederic E. Ives, illuminating engineer, has devised a colorimeter which indicates the percentages of the components of color composing the spectrum of differ-

ent sources of light. The following table, presented by Dr. Herbert E. Ives in a paper before the National Illuminating Engineering Society, gives the results of measurements made on 21 different sources of light, expressed in terms of average daylight as observed during an interval of three weeks. This table enables the light

COLORIMETER READINGS ON VARIOUS SOURCES

Source	Red	Green	Blue
Average daylight	100	100	100
Blue sky, mean of five sets	100	106	120
Overcast sky, mean of four sets	100	92	85
Sunlight, 2 P.M., August 19	100	95	68
Sunlight, afternoon observations, 2 to 5 P. M.	100	91	56
Nichols' average daylight (acetylene flame and A. O. Co. blue glasses 5 and 1)	100	69	42
Carbon arc, direct current	100	64	39
Mercury vacuum arc (Cooper-Hewitt)	100	130	190
Moore carbon dioxide tube	100	120	520
Welsbach mantle, 1¼ per cent cerium	100	81	28
Welsbach mantle, 2¾ per cent cerium (Mantle preferred by Welsbach Co. for residential illumination)	100	69	14.5
Welsbach mantle, 3¼ per cent cerium	100	63	12.3
Tungsten lamp, 1.57 watts per mean spherical c. p.			
Tungsten lamp, 1.25 watts per mean horizontal c. p.	100	55	12.1
Nernst glower, bare, 118 volts, .4 ampere	100	51.5	11.3
Acetylene flame	100	50	10.4
Tantalum lamp, 2.5 watts per mean spherical c. p.			
Tantalum lamp, 2.0 watts per mean horizontal c. p.	100	49	8.3
Graphitized filament, 3.1 watts per mean spherical c. p.			
Graphitized filament, 2.5 watts per mean horizontal c. p.	100	48	8.3
Glow lamp, 3.9 watts per mean spherical c. p.			
Glow lamp, 3.1 watts per mean horizontal c. p.	100	45	7.4
Flaming arc	100	36.5	9
Helium tube	100	37	9
Gas flame, open fish-tail burner	100	40	5.8
Moore nitrogen tube	100	28	6.6
Hefner	100	35	3.8

from any illuminant to be measured and compared with that from any other. For instance, assigning to the red, green, and blue light in white light separately arbitrary values of 100, the light from a gas flame is found to be $r=30.7$, $g=38.7$, and $b=19$; the light from a Nernst glower has corresponding values of 44.7, 71.7, and 56.3.

CHAPTER II

PHOTOMETRY—UNITS OF ILLUMINATION

The determination of the light emitted by a lamp is always made by comparing a beam of light from the given lamp with a beam of light from a standard lamp. The comparison of the total light in a beam from a given lamp with the total light in a beam from a simple lamp is called simple photometry; while the comparison wave length by wave length is called *spectro-photometry.*

An inherent difficulty in simple photometry is that different lamps show differences of color, which differences of color do not disappear when the attempt is made to adjust a photometer to show equality of light.

The photometer exists in numerous forms, the essential part of all types being a screen and accessories. The function of the screen is to reflect or diffuse the illuminations under comparison and it may be viewed directly by the eye unassisted, or through the aid of some optical device. The screen generally reflects less light than it receives, which may or may not be of the same quality. Selective absorption is generally made use of, whereby reflected light from an appropriately colored surface agrees in color with the compared light. The sensitiveness of the apparatus increases with the reflecting power of the screen.

Photometers may be divided into two general classes: First, visual acuity photometers or *illuminometers,* which measure the light by the ability of the eye to detect objects

illuminated by it; secondly, photometers in which the light to be measured is compared with that of a known source, the accuracy of this type being governed by the ability of the eye to determine equality of illumination. Illuminometers are adapted only for approximate measurements as they introduce personal equation and "Purkinje effect" errors, the latter of which are especially conspicuous at low intensities.

Only photometers of the second type give accurate results. Such instruments consist of a photometric device, a standard source of light, a means of varying the intensity upon the photometric device, and a reflecting screen or translucent plate for receiving the light to be measured. The photometric devices may divided into three classes: (1) Those in which the two light sources illuminate two adjacent fields with a sharply defined separating line. This class of photometers are simple and inexpensive, but they lack sensitiveness and ease of manipulation; (2) photometers with partially translucent screens, illuminated on one side by the comparison lamp and on the other by the unknown source, the two sides being presented in the range of vision as adjacent surfaces by means of mirrors or prisms. The principal photometer of this class is the Bunsen, which will be described presently. The third class of photometers consist of a set of prisms through which the illumination due to two sources can be viewed in one field. They are the most accurate and easiest in manipulation of photometric devices, but are expensive and difficult to construct. The best known and perhaps most widely used photometer of this kind is the Lummer-Brodhun. The third group of photometers are more sensitive to the measurement of low intensities than any of the others, and are applicable with fair sen-

sibility to the measurement of illuminating intensities far below the range of the first two groups.

The Bunsen Photometer, although one of the earliest used and simplest forms of photometers, continues to be widely employed as a highly efficient device for comparing the intensity of luminous sources. The light sources are placed at fixed points at opposite ends of a bar. The screen is movable and is placed in the photometric axis. The screen in its simplest form consists of a sheet of white paper made transparent with paraffine or some similar substance. The transparent portion is circular or star-shaped and has sharply defined edges. The light falling on either side of the screen is partly reflected from the white part of the screen and a portion passes through the translucent spot. When the illumination on both sides of the screen is the same an equal quantity of light is transmitted through the spot in each direction, and if the light from each source is of the same color the transparent portion of the screen should appear identical to the untreated spot. The screen is observed simultaneously on both sides by means of two mirrors properly arranged. The mirrors must have the same reflecting power and make the same angle with the screen. The arrangement of mirrors and screen is clearly seen in the drawing, Fig. 1, where *e* is the eye-piece through which both sides of the screen are observed by means of the mirrors *m m*.

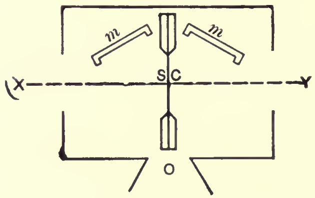


FIG. 1.—Bunsen Photometer.

The Lummer-Brodhun Photometer uses, instead of the photometrical grease-spot of the Bunsen photometer, a purely optical arrangement. The combination of parts

is shown in Fig. 2. A high-reflecting-power diffusing screen is placed in, and with its plane normal to, the photometric axis. This screen is observed on both sides by means of the optical device which presents both sides of the screen as adjacent fields. The diffused light, reflected from the sides of the screen s' and s'', strikes against the mirrors f_1 and f_2 and is reflected along the normal to the surface of the triangular prisms A and B. The observer looking through the telescopic tube o, directed normally to B, clearly views the interior surface $acdb$ of the prism B.

Mirror

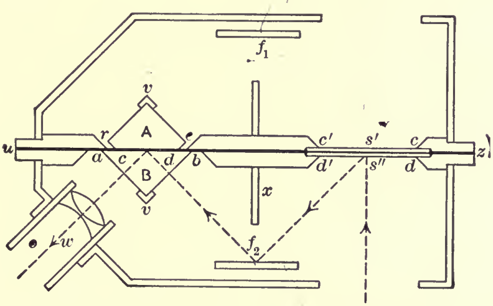


Fig. 2.—Lummer-Brodhun Photometer.

Mirror

The light from f_2 will be wholly reflected to o from the portion of the surface bd and ac, while that falling on cd will be transmitted through A and will not appear in the field to be compared. That portion of the light from f_1 which falls on cd will be transmitted through B to o, while the light falling on the parts nc and de will likewise be reflected out of the field of vision. The observer will then see a three-part field, the central part being illuminated by light from f_1; the other portions receive light reflected by the mirror f_2.

The number of photometers is legion, and it is outside the province of a treatise of this nature to discuss their

various modifications. For an exhaustive discussion on photometers the reader is referred to Prof. Wilbur M. Stine's, "Photometrical Measurements," Barrow's "Electrical Illuminating Engineering," and Palaz's "Industrial Photometry."

Obstacles to Accuracy in Photometric Measurements.—Photometry as usually understood concerns itself with the measurement of the power of creating brightness on the part of the light tested, and assuredly is its most useful *but not its only function.*

In the case of differently colored sources of light, the average observer finds it very difficult to decide when the two photometrical surfaces appear equally bright. It has been known to physiologists for some time that the central portion of the retina, the "macula lutea" or "yellow spot" as it is termed, is less sensitive than the surrounding portion to the green end of the spectrum. Let us suppose then that the image of the surfaces in a photometer illuminated by two sources which differ in color, is received upon the retina, and we adjust the position of the photometer until the two surfaces appear equally bright. Now, if we walk away from the photometer so that the image of the illuminated surfaces falls more toward the centre of the retina, this equality of brightness is found to exist no longer. The redder of the two lights now appears the brighter. If we maintain the distance of the eye from the photometer the same, but select a photometer in which the photometrical surfaces are different in size from those previously used, we may again come to a different conclusion, for the portion of the retina occupied by the image of the illuminated surface is again changed. In working with more or less pure colors the effect may become quite marked.

This so-called "yellow-spot" effect is well known to those who have studied color photography, but its importance from a practical view-point is hardly realized. In the experiment mentioned, differences of as much as 100 per cent could be readily produced. Mr. J. S. Dow states that differences between 20 and 30 per cent have been observed by him when comparing a mercury-vapor lamp with a carbon-filament lamp.

The "yellow-spot" effect is attributed to the irregular distribution of the rods and cones over the retina, because the variations in the relative brightness of two "heterochromatic" surfaces can be ascribed to the variation of the proportions of rods and cones on the portion of the retina on which they fall. There are numerous differences of opinion about the physiological peculiarities of the eye, and these, with many minor peculiarities of the eye, affect the photometric comparison of sources of light differing noticeably in color. We have much yet to learn as to the possible uses of light from different portions of the spectrum and we have yet to devise satisfactory and universally recognized methods by which the value of these portions of the spectrum for special purposes can be determined.

Candle-Power.—The unit by which the luminous intensity of sources of light is expressed is termed candle-power. The unit of candle-power is derived from standards preserved by the National Bureau of Standards at Washington, D. C., for the United States. Each country in Europe of any importance maintains a national standardizing laboratory; that of Germany, termed the Reichsanstalt, being the most widely known on the Continent.

The Lumen-Candle.—The maximum flux of light from a source is equal to the mean spherical intensity multiplied by 4 Π (Π being equivalent to 3.1416). The unit of flux is

termed the lumen-candle. (Lumen or unit of flux is defined as the light on one square meter having a uniform intensity of one lux.) A lumen candle has a value of $\frac{1}{4}\Pi$ times the total flux of light emitted by a source possessing a mean spherical intensity of one candle-power.

Meter Candle.—The unit of illumination is the meter candle, which is the normal illumination produced by one unit of candle-power at a distance of one meter (about 39.37 inches).

Foot-Candle.—Illumination is frequently expressed in foot-candles. A foot-candle is the normal illumination produced by one unit of candle-power at a distance of one foot. A foot-candle is equivalent to 10.764 meter candles.

Watts per Candle.—The specific consumption of an electric lamp is its watts consumption per mean spherical candle-power. The term "watts per candle" is the expression used commercially in connection with incandescent lamps and denotes watts per mean horizontal candle-power.

The basis for comparison of various illuminants with each other is either the total flux of light in lumen-candles or the mean spherical candle-power, unless there is a positive stipulation to the contrary. Unless clearly stated otherwise a standard circuit voltage of 110 volts or a multiple of it may be assumed.

The Efficiency of Electric Illuminants is properly stated in terms of mean spherical candle-power per watt at the lamp terminals. The definition of efficiency as applied to artificial illuminants is not strictly correct, as no means of determining the energy equivalent of light has as yet been devised. In practical illuminating work efficiency is understood to mean the candle-power per watt.

Efficiency of illumination may be defined as the com-

bined effect of three different kinds of efficiencies, viz.: (1) Efficiency of visual perception, or the efficiency with which the eye receives light energy and transforms it into visual perception; (2) efficiency of light distribution, or the relation between total light energy generated and the light energy useful in producing desired conditions for visual perception; (3) efficiency of the light source—*i.e.*, the efficiency with which the chemical or electric energy is transformed into light energy. Visual perception efficiency is influenced by three conditions: (1) The intrinsic brilliancy of the light source and the light-reflecting objects; (2) the color of the light; and (3) the steadiness and intensity of the light. Analyzing the conditions still further, it should be stated that efficiency in light distribution depends upon three important factors: (a) The distribution of light emitted by the illuminating unit; (b) the size of the unit; and (c) the locations of centres of light distribution.

The Economy of Electric Illuminants is a term sometimes used in a synonymous sense with efficiency, but is more properly applied when referring to costs. Thus one system of lighting is more economical than another if it is capable of producing the results at smaller cost. Thus, for instance, lighting by kerosene oil may be more *economical* than lighting by electricity, although one may not be able to state what the relative *efficiencies* of the two systems are.

CHAPTER III

METALLIC FILAMENT AND ELECTROLYTIC INCANDESCENT LAMPS

Retrospect and Introspect.—The commanding importance of the tungsten lamp at the present moment in the electric light industry is one of the most astonishing events in the history of artificial illumination. After more than twenty years' usage of the ordinary carbon filament incandescent lamp that underwent but slight improvements in efficiency during that time, and with arc lamps that degenerated from the one watt per candle-power open arc, to the almost three watts per candle of the enclosed alternating-current arc, it is remarkable that artificial illumination should suddenly and almost simultaneously be produced with substitutes for both types with an increase of efficiency in both cases greatly exceeding the most extravagant hopes of the optimists in the art of illumination.

Hardly more than two years since electric lighting officials believed that the changes of lighting-plant business policy to adapt the industry to the new situation introduced by the metallic filament lamps, might gradually be made on account of the slowness of manufacturers in supplying these lamps. At this writing, however, the supply of the new incandescent lamps is approaching the 125,000 mark per day, which number is being further increased by the importation of foreign lamps, while the output is being increased daily. With the present large

and growing rate of production, and the fact that the new lamps have a life more than twice that of the carbon lamp, with at least two-thirds less energy consumption, it should not be more than a few months before the heavy demand for the new illuminants will be met. At present most attention is centred on the higher candle-power metallic filament lamps, principally for the reason that they offer admirable means for supplanting gas arcs and carbon electric arc lamps for street and commercial lighting, although the betterment of the art by the introduction of metallic filament lamps for interior illumination as substitutes for the ordinary carbon filament lamps is receiving constant attention.

The rapid introduction of the new lamps is somewhat augmented by the fact that the present cost of the lamps is not given great weight in formulating the policies of lighting plants. The price of metallic filament lamps in Europe was halved almost within a year, and as monthly notices of further reductions are being made, there is no reason for believing that the present scale of prices will be maintained in this country.

It can be safely stated that the metallic filament lamps are on a practical commercial basis, and are factors in the lighting field that cannot be ignored, and that bid fair to supplant all other illuminants where electric service is available.

The aim of scientists and inventors since the introduction of the carbon filament lamp has been to produce a light source which would broaden the field of electric lighting. The attainment of this end has, up to the present time, been reached with the metallic filament lamps, particularly the tungsten filament lamp. How early these new illuminants will, by the constant process of evolution, be

supplanted by lamps of higher efficiency the future alone can tell. Investigators never attain the goal of their efforts and the encouraging results obtained with still other rare minerals when employed for incandescent lamp filaments engender the belief that it will be only a few years before the present methods of incandescent lamp lighting will be radically improved.

The desideratum in the development of artificial illuminants has been to produce a light source of maximum efficiency or, in other words, a light with the minimum of heat—a "cold light" like that with which Nature has endowed the firefly of our summer evenings. The goal, while considerably in the future, is much nearer than it was ten years ago.

This commercial application of the so-called high-efficiency lighting sources has directed the attention of the manufacturers of various illuminants, such as the Nernst, Gem, tantalum, Cooper-Hewitt, and other vapor lamps, away, for the time being, from the problem of efficiency, and centred it upon the quality, color values, and uses of these light sources. Such a hiatus in the problem of efficient development of electric illuminants has greatly benefited the æsthetic side of the art. Prior to the time that the tungsten lamp was put on a commercial basis, the electric lighting art, if not, in fact, the whole art of artificial illumination, was in the embryonic state. The expensive and frequently prohibitive cost of installation and operation, together with very unsatisfactory light quality and poor efficiency of the high candle-power lamps then available, retarded agreements as to a true standard of illumination. The advent of the Gem and tantalum high candle-power lamps inaugurated a marked improvement, since at one stroke the economy and illumination

by electricity was improved, and the new era of single-unit illumination dawned.

At this stage of development the value of reflecting and diffusing shades and reflectors was revealed. The high intrinsic illumination emitted by the new filaments, coupled with their concentrated brilliancy, rendered essential the use of some arrangement to direct the light radiation where it would be usefully employed for the purpose desired. This necessity created the new art of reflector design in which scientific requirements had to be met. The day of the white enamelled cone and the flat glass plate, which crude aids to uniform light distribution served the carbon filament lamp after a fashion, had passed. At first glassware of curious shapes and sizes was evolved, but on account of its high absorptive power proved more or less unsatisfactory. The solution was found in prismatic glassware in which the well-known principles of refraction and reflection are utilized uniformly to diffuse the light instead of merely reflecting it.

It is quite a singular fact that the initial invention of the metallic filament lamp was made in the United States, although the commercialization of the lamps has remained to be made by European scientists. The daring and skill of American manufacturers has, however, resulted in our equalling if not excelling Continental concerns in the perfection of the details of metallic filament lamps. In the case of prismatic reflectors, however, the reverse is true. While the original prismatic reflectors were imported from Europe, the ingenuity of American manufacturers has perfected the methods of manufacture. The scientific principles of illumination are being developed as an art instead of being utilized as *mere details of lighting arrangements*.

The metallic filament lamps have begun to displace a number of other illuminants, both gas and electric, and for interior as well as exterior illumination. For interior lighting their high candle-power as well as illuminating values renders possible the adoption of more delicate and harmonious color effects than ever before attained. Even in art galleries where the peculiar requirements of proper artificial light have been unsatisfactorily met by other light sources, the metal filament lamp has given the proper results. The new incandescent lamps are also gradually making the open and closed types of arc lamps—gas and electric—for street lighting obsolete. As an aid to department stores, tradesmen and shopkeepers of all kinds, the value of the metallic filament lamps, when properly installed, is evidenced by the natural effect it produces in displaying wares to the best advantage.

Despite the growing field of usefulness which the tungsten lamp serves, it is likely that the carbon incandescent lamp will continue to be utilized to a certain extent, for lighting where economy is no great object, and in the numerous sockets where intermittent lighting only is required. This is evidenced by the fact that the output of carbon incandescent lamps in 1907 was equal to that of the boom year of 1906.

The possible limits of incandescent electric lamp efficiency appear to have been reached in the newer types of metallic filaments described in the chapter to follow, yet who knows but that lamps using more refractory substances or giving more selective radiation of light will be produced ? At the present time it would seem that the only recourse for still improving the luminous efficiency of incandescent lamps is either in the production of refractory materials with higher temperatures of volatiliza-

tion for working limits, and of melting for margin of overload; or, in the discovery of a filament having selective radiating properties, or, in other words, one which will radiate more within the visible range of frequencies and less within the invisible range. The two features desired are not necessarily interdependent, as the property of resisting higher temperatures without melting may be separate and distinct from the property of selective radiation. Perhaps no advantage will be found in selective radiation, in which event the use of highly refractory filaments will become necessary. If the solution of the problem of gaining still higher efficiencies in electrical illuminants is attempted by departing from the single incandescent lamp, the outlook is better for obtaining higher efficiencies from incandescent gases on account of the fact that all such gases radiate selectively. Hence the future for the lamp of glowing vapor appears brighter than that of the lamp of the glowing solid.

Ores from which Tungsten is Obtained.—Tungsten, or Wolfram, is a metal discovered in 1871 and named from the Swedish "tung" (heavy) and "sten" (stone). It is not found native but occurs as tungstate of iron and manganese in the mineral "wolframite," and as the calcium tungstate. The fusing point of tungsten is higher than that of any other known metal, which enables it to operate at the very high efficiency obtained in the tungsten lamp. One of the laws of incandescent light is that the higher the temperature the better the light and the greater the economy of current consumed.

The principal tungsten minerals are wolframite, a tungstate of iron and manganese, and scheelite, a tungstate of calcium. Both minerals, like tin ores, occur as a rule in quartz veins cutting rocks containing much

silica, such as granite and rhyolite, but some apparent exceptions to this rule are found, as for instance in New Mexico, where hübnerite and a small amount of scheelite occur with pyrite and lead minerals in a vein cutting limestone; and at Nome, Alaska, where scheelite is found in the gold placers in a region of schists several miles from the nearest granite outcrops. The greater part of the American tungsten product in 1907, 1,640 short tons, valued at $890,048, came from the mines in Boulder County, Col., which reported an output of 1,146 tons of wolframite valued at $573,642.74. In California, which was the second State in order of production, the output was in the form of scheelite, as was also most of that from Montana. The total scheelite reported was 414 short tons. Small amounts of tungsten ores were also produced in Washington, Nevada, Arizona, and probably in New Mexico. Considerable tungsten is also mined in Australia, New South Wales, South Africa, and New Zealand. The output in Australia was 1,643 tons.

Up to four years ago tungsten was known only in laboratories and then only in a very impure state, and on account of its rarity the price was very high. But latter-day prospecting has resulted in the finding of vast bodies of the ore and the price has correspondingly dropped to about $7 a pound. It would be even lower than this but for the difficulties in refining the metal. Only with the electric furnace is it possible to produce tungsten in its pure form. Pure tungsten is hard enough to scratch glass; it is almost impossible to melt it; it is malleable to some extent, but not ductile. Because it cannot be drawn into wire the wire-like filaments in the electric lamps are made by the "paste" process, which consists in mixing the powdered metal with binding or stiffening agents such as gums,

dextrine, etc., until the mass has the consistency of putty. It is then squirted through a very fine orifice in a diamond with a pressure of several tons to the square inch. The result is a somewhat moist thread which has enough coherence to be formed into filaments which do not break while being dried. The filaments are first heated, then subjected to an electric current which causes them to sinter. The process of sintering is carried out in gases which chemically attack all the constituents of the binding agent, without the metal being affected, so that eventually a filament of pure tungsten remains.

Physical and Electrical Properties of Tungsten.—Tungsten (in German, wolfram, and sometimes so termed in English-speaking countries), is one of the rare metals, is of iron-gray color and is so very hard that it can scratch glass. Its specific gravity is 19.1 (nearly similar to that of tantalum), thus being one of the heaviest of metals. It was discovered by Scheele in 1780. Until very recent years tungsten has been known to most electrical engineers only as the metal which, when added to German silver to the extent of one or two per cent, made the alloy platinoid, which possesses a remarkably high resistance, the value of which varies only slightly with great temperature changes.

Similar to osmium and tantalum, tungsten has a lower resistance than carbon, which gives rise to the same difficulties in producing high-voltage lamps of tungsten there are in producing high-voltage lamps of osmium and tantalum. Pure tungsten does not melt, but volatilizes directly at a temperature considerably in excess of that at which the ordinary carbon filament is supposed to volatilize. This accounts for the marked increase in luminous efficiency of the tungsten lamp as compared with the carbon filament lamp. The melting-point of

tungsten filaments has been determined by Waidner and Burgess to be 3200° C.

Tungsten is commercially obtainable in the form of a fine powder. The ductility of the metal is so low that it is impossible to draw it directly into a fine wire, which is quite practical with a tantalum filament. Tungsten unites readily with oxygen and with carbon at high temperatures. Hence the problem of producing tungsten filaments is extremely difficult.

The Auer Process of Making Tungsten Filaments.—The processes and methods employed in the manufacture of tungsten lamps are both numerous and diversified, and while the majority of these are still in the experimental stage a number are in successful use and deserve detailed discussion.

In the "paste process," originally developed by Auer in the manufacture of the osmium lamp, which will be treated of later, finely divided tungsten is mixed with a suitable binder and the resulting paste is forced through diamond dies under powerful pressure. The paste is thus shaped into the proper form for a filament, which is then heated in an atmosphere of steam and hydrogen to remove the carbon in the binding material, the refined filament consisting of almost pure tungsten.

Just-Hanaman Process.—In the process perfected by Doctors Alexander Just and Franz Hanaman, patented May 28, 1907, which is used in the manufacture of the Just lamp (Fig. 5), a large number of which are in use in this country, a fine filament of carbon is heated in the presence of finely divided tungsten or some tungsten compound which is readily reduced by carbon to a metal. The compound of the metal may be either tungsten oxide, tungstic acid, or tungsten sulphide. The tungsten com-

pound is mixed with an organic binding material, such as a solution of cellulose in chloride of zinc, collodion, coal tar, or the like. The filaments are then formed by pressure through a die in the usual manner, and afterward (subsequent to denitration, if collodion is employed) the filaments are carbonized. The quantity of tungsten compound used in the mixture is such that in the finished filament sufficient carbon is always present to impart the necessary strength to it, as the filament depends upon the carbon alone for strength to withstand the subsequent treatment. The specifications state that efficient filaments are obtained if from 2 to 10 grams of tungstic acid are added to a solution of 10 grams of cellulose in 260 grams of chloride of zinc whose specific gravity is 1.83. This mixture is then formed into filaments and carbonized in the absence of air and is then subjected to the following additional treatment. An electric current is passed through the filament in an atmosphere of the vapor of one of the oxyhalogen compounds of tungsten, such as tungsten oxychloride, in the presence of a little free hydrogen. Incandescing of the filament causes a reaction whereby the carbon still retained in the filament is replaced by tungsten.

Kuzel Process.—This process, the invention of Dr. Kuzel, a German electro-chemist, consists in forming an arc between tungsten electrodes under water or possibly some other liquid, forming a so-called colloidal solution, which is then brought to the proper consistency and squirted through diamond dies. The chief advantage of this method over the two preceding ones lies in the absence of any organic matter, which, when present, is completely removed only with the greatest difficulty, and if allowed to remain tends to reduce the life and serviceableness of the

filament. The American rights to this process have recently been been acquired by The General Electric Company.

General Electric Process.—A very radically different method from these two is that patented by the British Thomson-Houston Company and perfected by The General Electric Company in this country. By this process the metal tungsten is rendered sufficiently ductile to be drawn into a wire, which prior to this has been considered impossible. The method consists in reducing an oxide of tungsten and mixing the powder thus obtained with an amalgam of cadmium and mercury. The plastic mass which is made is pressed through a die in the usual manner and the cadmium and mercury are then driven off by heat. The filament so formed possesses the usual brittleness, but after being heated to a moderate temperature, it becomes pliable and may be readily bent into any desired form. It is claimed that it is possible by this process to draw tungsten wire from rods of the metal prepared as above described by simply maintaining the metal and the dies at the proper temperature. This method is, therefore, one of the most promising in use at the present time, as the fundamental difficulty in the making of tungsten filaments is that tungsten is not ductile and unites readily with carbon and oxygen.

In a patent granted to Mr. Charles Van Brunt on Dec. 17, 1907, and assigned to The General Electric Company, a method of purifying tungsten trioxide is given, which admits of rapid refinement of the material and indicates a probable development of the tungsten lamp. The process is one of fractional precipitation, use being made of organic bases for the precipitation. In the ordinary methods of repeated evaporations and crystallizations

the purification necessary requires a week or two, while by the Van Brunt method a complete batch of oxide is purified in a day. The refined oxide is by this method an almost fluffy, impalpable powder and is reduced to metallic tungsten by means of hydrogen. The patent claim states that filaments made in this way are "strong, free from cracks and imperfections, and for a short time, at least, will operate at a temperature corresponding to a specific consumption of only a few tenths of a watt per candle."

The Lux Process.—This method, developed by J. Lux, is used in the manufacture of tungsten lamps at the inventors' lamp factory in Vienna, Austria. It consists in mixing finely powdered metallic tungsten with powdered zinc oxide (ZnO_2) or zinc sulphide (ZnS) and an organic binding material. The quantity of the latter is limited to prevent the finished filament from containing carbon. The mixture is then made into a paste which is formed into filaments, and the resulting filaments heated in the absence of air. These filaments are then raised to incandescence by passing an electric current through them in an inert atmosphere or in a vacuum; the zinc oxide or zinc sulphide (depending on which is used) reacts with the carbon, and carbon monoxide and zinc vapor are given off. The filament is caused to contract considerably by this process and sinters together.

In some of the processes discussed the filament produced is not of uniform diameter and tests must be made to find such weak points. The Lux process for detecting this weakness is as follows: The long filament wire is electrically treated for about a second in air of predetermined temperature. Any weak points which have a reduced cross-section become light and are at the same time oxid-

ized, so that when cooled they show the color of the oxide and can be eliminated.

The "Z" Tungsten Lamp is a type in which finely divided tungsten is squirted with an organic binding material through dies, the organic material being subsequently removed. The lamp (Fig. 7) is of the multiple filament pattern, the filaments being in the shape of a hair-pin, grouped around a central glass support and connected in series. The filaments are supported by carbon hooks attached to the centre stem by thin steel wires. The combination of steel wire and carbon hook forms a spring support which compensates for the expansion and contraction of the filament, and at the same time dampens the vibrations. To prevent blackening of the lamp a "special salt" is painted on the central glass stem. The initial consumption of the "Z" lamp is claimed to be 1.15 watts per candle, with an average loss of one per cent in candle-power for each 100 hours of burning.

The Siemens and Halske Process for Making Tungsten Filaments.—In this method (very recently patented) nickel tungstate is mixed with tungstic acid or with some plastic tungsten compound, so that after reduction by heating to a temperature of about 1650° C. in an atmosphere of hydrogen, the final alloy contains about 12 per cent of nickel and 88 per cent of tungsten. This alloy of nickel and tungsten is ductile and can be drawn or rolled. After drawing the nickel is expelled by heating the filament electrically in a vacuum.

The Heinrich Process.—This process, due to Herr W. Heinrich, is interesting in that the inventor uses a binding material free from carbon in the paste. The mixture consists of 50 grams of dry, pure, powdered sulphur with 60 grams dry amorphous phosphorus, the mixture being

carefully heated until a chemical reaction takes place, yielding a pasty substance which is of high fluidity at about 200° C. and evaporates at a temperature above 400° C. Fifteen grams of pure amorphous metallic (tungsten, etc.) powder are intimately mixed with three grams of this phosphorus-sulphur compound. In this way there is obtained an elastic rubber-like material which can be easily pressed into very thin filaments. These filaments are heated in vacuo, whereby the largest quantity of the binding material distils off at a temperature of from 400 to 500° C. A small portion remains in the filament in the form of metallic phosphide or metallic sulphide. This chemical reaction holds the metallic particles very strongly together. If the filaments are then heated in an absolute vacuum to a temperature of over 1,000°, the filaments sinter together and the metallic phosphide and sulphide are reduced to pure metal. The filament thus obtained is stated to consist of pure metal without any traces of carbon.

Recent Bolton Process for Making Metallic Filaments.—On July 13, 1909, a patent was granted to Werner von Bolton, inventor of the tantalum lamp, on a process for the manufacture of tantalum, tungsten, and other metallic filaments, in which process a ductile metal such as nickel or copper initially enters.

The specifications assert that in order to convert metals which when present alone can be moulded only with great difficulty—as for instance tungsten, tantalum, molybdenum—into suitable shapes for electric incandescent lamps, the metal is embedded in a state of fine division in another metal, such as copper, thorium, gold, aluminum, and especially nickel, in such a manner that each of the finest particles of the refractory metal is enveloped in a casing

of the other metal. The metallic mass so obtained is then made into the form of filaments mechanically by rolling or drawing; or, under some conditions, by pressing, squirting, etc. The enclosing metal is subsequently removed by chemical or mechanical means or by vaporization.

A metallic powder can be embedded in another ductile metal in a number of ways, as for instance, by placing the metallic powder in a molten mass of the other metal and uniformly distributing in the latter; or by a powder of the one metal being intimately mixed with a powder of the other metal and subsequently united by pressure. The application of pressure to the mixed powder causes the ductile metal to yield and unite into small plates which cohere and form a covering or casing for the non-ductile metal. This coherence can also be effected in the latter case by the mixture of metallic powders being subsequently heated in such a manner that the ductile metal, which is assumed to be less refractory, is converted into one cohesive mass by its parts being welded or sintered together, or by its parts being united in a molten state, which cohesive mass envelops the particles of the metallic powder of the highly refractory metal.

The removal of the enveloping metal can be effected—provided the enveloping metal is not employed in too great excess—by sending an electric current through it by which the filament is heated, so that the enveloping metal is volatilized. The residue of the metallic particles then sinter together into one filament. Should another metal be used as an encasing metal which itself possesses a very high melting point, this can remain in the finished filaments. Among the easily ductile metals thorium is especially recommended on account of its high melting

point and the ease with which it can be worked mechanically.

Support of Tungsten Filaments.—On account of the low resistance of tungsten the filament must be either of very small cross-section or of considerable length. To make the filament of suitable length for use in incandescent lamps a compromise between these two alternatives must be made. Even then the length of the filament is so much greater than that of the carbon incandescent lamp, and the tungsten filament is so soft when heated, that a radically different method of supporting tungsten filaments is used from the ordinary method employed in carbon lamps.

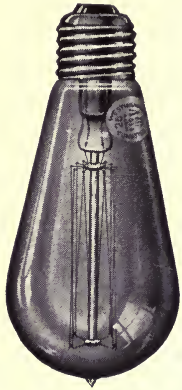


Fig. 3.—Usual Arrangement and Support of Tungsten Filaments.

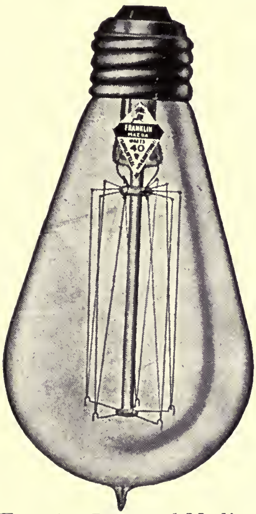


Fig. 4.—Low and Medium Voltage Lamp.

The universal method of arranging and supporting tungsten filaments is shown in Fig. 3. A series of lateral wires are fused at the two ends of a central glass rod which is an extension of the glass rod in which the leading-in wires are fused. The filament is passed through loops in the supported wires, the shape and arrangement of the loops differing slightly in the lamps of foreign makers, but presents nearly the same design

as in American-made lamps. Thus in the lamp, Figs. 4 and 5, the arrangement of the loops differs slightly in the low voltage lamp (Fig. 4) from that of the high voltage lamp. The supports and arrangement of the loops in the high and low voltage lamps are shown in Figs. 6 and 8. The loops for supporting the lower part of the filament of the Westinghouse lamp are shown in Fig. 8.

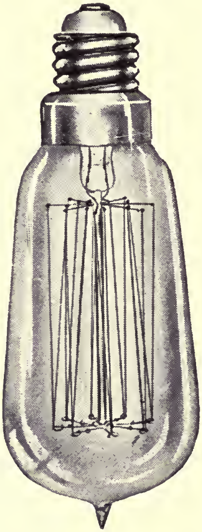


FIG. 5. — "Just" Tungsten Lamp for High Voltage Circuits.

In a patent granted to the British Thomson-Houston Co. May 24, 1909, the lower ends of the loops are welded to metal arms radiating from the base of the pedestal. A number of short copper wires fixed vertically on top of the pedestal support horizontal fixed pieces of nickel wire. Each nickel arm carries at its extremity a small loop of tungsten or molybdenum, through which the filament passes. The nickel wire acts as a spring holding the filament in tension, and can be joined to the supporting loop by winding the end around the crossed legs of the loop. The other end is

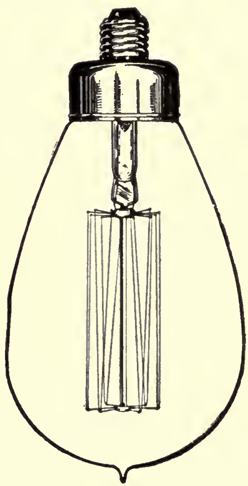


FIG. 6. — Method of Filament Support in General Electric High Voltage Lamp.

welded to the copper support. The supporting loop and the nickel wire are made with diameters slightly larger than the diameter of the filament.

A patent for a metallic filament support was granted to H. Hoge on March 11, 1909, which possesses novel features, and which method it is stated will be used in the manufacture of the "Z" tungsten lamp. (Fig. 7.) The support consists of a circular base of glass or porcelain, with small holes all around its periphery, which is fixed in the neck of the lamp, and the resilient supporting wires, insulated from each other, rise from the centre of this base. A leading-in wire enters the same hole in the base as the beginning of one filament loop and is welded or cemented to it. The end of the first loop enters the same hole as, and is cemented to the beginning of, the second loop, and so on. Each loop is supported at the top by being passed through a ring at the extremity of the supporting wire. Two separate circular bases, one for the supports and the other for the filaments, may be fixed in the neck of the lamp, each being pierced at the periphery as desired.

FIG. 7.—American "Z" Lamp.

A patent was recently granted Mr. John W. Howell, Chief Engineer of the Edison Lamp Works, for a method of making joints between tungsten lamps and leading-in wires, which differs in slight details from the methods above described. In Howell's method the end of the nickel wire is bent into a hook, and the end of the filament,

previously coated with a paste of finely divided tungsten or copper mixed with gum arabic, is placed in the hook. An arc is drawn from the extreme end of the hook and a globule of fused metal runs into the corner of the hook, thereby fusing the filament and paste together. A portion of the coating above the joint is merely hardened and appears to prevent the filament from breaking at the joint. The joint can also be made by heating the hook to a white heat.

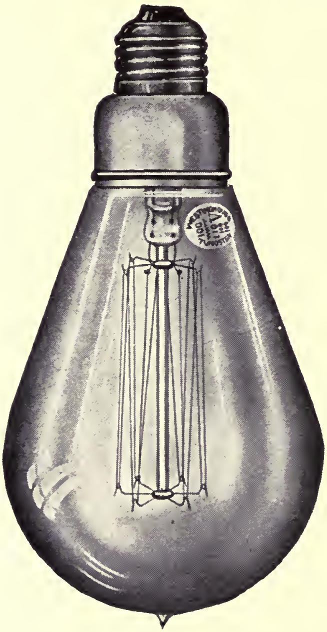


FIG. 8.—Loop Support of Filament of Westinghouse Tungsten Lamp.

The "wire type" of tungsten lamp filament due to the engineers of the Westinghouse-Lamp Company, is shown in Fig. 9 in comparison with the form of arrangements of filaments commonly used. (Fig. 10.) The main elements of the former are a single long filament, intermediate hook supports which hold the filament loosely, and a terminal which is sometimes mechanically and electrically adequate. The common tungsten lamp consists of a number of filaments in series, the individual filaments having their ends fused together to stiff supporting wires. The new lamp adopts a method of overcoming the disadvantages of this method, namely, by employing a single filament and so mounting it that the filament is not rigidly

fastened to supports. The single filament is wound back and forth around hook supports at numerous points, and a few turns near each end wound in the form of a spiral spring around the respective leading-in wires, and the ends fused. The several turns of the filament around the leading-in wires act as a sort of a spring, so that a slight bending of a

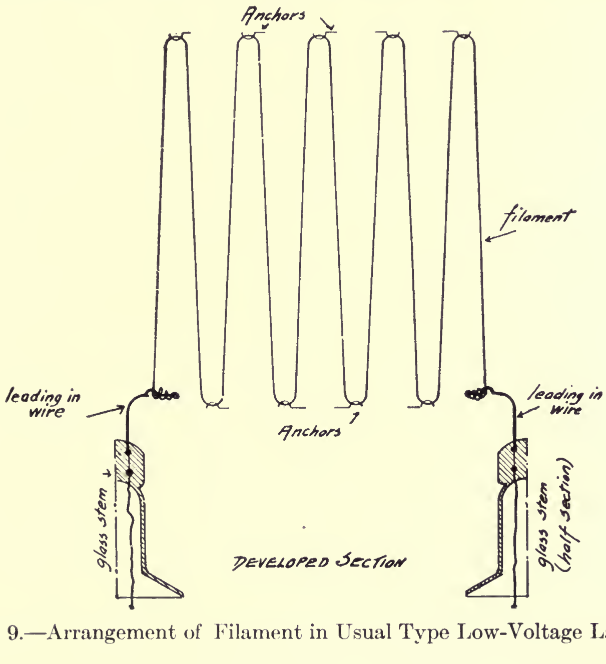


FIG. 9.—Arrangement of Filament in Usual Type Low-Voltage Lamp.

filament, resulting from a blow or vibration, does not act directly upon the fused joint, as would be the case if the straight part of the filament came directly from the fused joint. Furthermore, carelessness in the act of fusing is stated to be of minor consequence in the wire type of lamp, whereas it might seriously lessen the strength of the filament in the common forms of lamp.

A tungsten lamp, using, say, five filaments, is analogous to five independent lamps in series, and its life will be fixed by that of the weakest filament. On the other hand, a process in which a yard or more of filament is made in one piece is not liable to the conditions which are possible and probable when a lamp contains several filaments

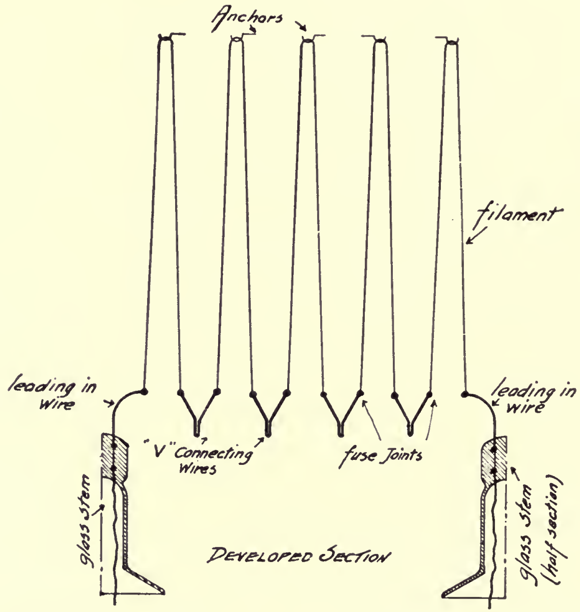


Fig. 10.—One Type of Arrangement of Filament in "Wire Type" Tungsten Lamp.

which have been made at different times, and under the necessarily different conditions incident to commercial manufacture. It is stated that the mechanical excellence of the new lamp is attested by the result of comparative experiments with such lamps and lamps of the ordinary type. Among these was a test consisting in dropping a

weight on a poplar board held on supports about four feet apart to which lamp sockets were attached. It was found that with the wire type the weight had to fall from four times the height to cause the same destruction as of the fused type of lamp. The mechanical tests in the aggregate showed that the wire type of lamp is much less liable to injury than the fused type where subjected to blows which are of a kind similar to those that may be expected in service. It is stated that the wire-type tungsten filament is made in long lengths, the present equipment making several miles a day.

Connections of Leading-In Wires for Metallic Filament Lamps.—Several methods for making a durable conducting connection between metallic filaments and the leading-in conductors have been patented.

In the alumino-thermic method of the British Westinghouse Filament Lamp Company, the joint consists of a metallic alloy produced at the point of connection. A mixture of the oxides of the metals which are to form the joint, with aluminum, magnesium, etc., with a suitable liquid or flux, is placed around the connecting points of the filament and the leading-in conductor. The ends of the leading-in conductors may be provided with hoops or loops, and the filament thrust into them. The connecting points are then covered with the mixture described above, and the alumino-thermic action is started either by means of the electric current or in some other way. The aluminum combines with the oxygen of the oxides and the heat evolved by the reduced metals fuses together the ends of the filament and the leading-in conductors. The aluminum forms a filament on the outside of the joint, which may be removed by dipping it into hydrochloric acid. The liquid or flux employed with the mixture must be of

such a nature that it will not exercise an injurious effect upon the material.

In Kuzel's process the filament is joined with the leading-in wires by means of a very refractory metallic carbide—as, for instance, chromium, tungsten, or magnesium carbide. If the ends of the filament are put into fused tungsten carbide, made by the special process of Moissan, the carbide passes into the pores of the carbon, and when the filament is removed the end is covered with a layer of the carbide, which may be made of any thickness by repeating the operation. The tungsten carbide need not be chemically pure, but it may contain from 1 to 6 per cent of carbon.

Treatment of Tungsten Lamps to Prevent Blackening.—The usual process of preventing blackening of the bulb during the lengthy exhaustion needed by metallic filament lamps is to keep up an atmosphere of phosphorus vapor in the bulb, the temperature being maintained at such a value that no phosphorus will be deposited. This is effected by coating the glass stem and the filament leads with finely divided red phosphorus admixed with alcohol and ether.

Methods of Increasing the Specific Resistance of Metallic Filament Lamps.—The comparatively low specific resistance of tungsten, tantalum, etc., which causes difficulties in the manufacture of metallic filament lamps on account of the very long conducting medium necessary, has led inventors to attempt to remedy this trouble by introducing various chemicals in such filaments.

In Kuzel's method a solid solution of boron, silicon, or carbon is incorporated in the filament. The metallic filament is heated white hot and is then brought into contact with a relatively small amount of either of the above-named substances. The boron, carbon, etc., is

quickly absorbed by it, but the metallic surface remains undiminished in brightness. This treatment increases the specific resistance of the metals from 3 to 10 times without changing their energy consumption. Its principal disadvantage is that the color of the light is changed thereby. For example, the use of carbon to increase the resistance imparts a golden or orange tinge to the light, while the use of boron causes the light to have a green tinge.

The method of the Allgemeine Elektricitäts Gesellschaft for increasing the specific resistance of metallic filaments is by means of oxides of the rare earths, *yttrium*, *ytterbium*, etc. Of these yttrium is said to be the most suitable, as the vacuum of the lamp is not interfered with and the life of the lamp is long. The amount of yttrium added must be at least 5 per cent in order to give a considerable increase in resistance, which may be raised as much as 40 per cent.

In the process of the British Thomson-Houston Co. (General Electric Co.) use is made of thorium oxide incorporated in tungsten. Finely divided tungsten powder and thorium oxide are mixed with an alloy of cadmium, bismuth, and mercury in the proportion of 35 per cent of the alloy to 65 per cent of the refractory material made up of tungsten and thorium oxide in various proportions. From only a few per cent to as much as 50 per cent, by weight, of thorium oxide is used. The alloy used as a binding agent is vaporized and the filament sintered together. It is stated that the resistance of a tungsten filament with an addition of 20 per cent of thorium oxide is about 50 per cent greater when heated than that of the pure tungsten filament under the same conditions. On account of the brittleness of thorium a filament cannot be easily welded to leading-in wires when the

percentage is as much as 50 per cent, and a paste made of fine tungsten powder and water-glass is used for making the connection. If the percentage of thorium oxide exceeds 50 per cent, the filament becomes very brittle, but possesses a very high resistance, so that very short filaments without supports may be used.

Useful Life, Radiating Power, and Temperature of Tungsten Lamp Filaments.—Of all metals which have been investigated up to the present time, only pure tungsten has a life as high as 1,000 hours when operated at about one watt per hefner candle-power. The following figures show an interesting comparison between the electrical energy consumed and the light radiated from the surfaces of tungsten and carbon filaments. One square millimetre of tungsten filament gives 0.5 candle-power and consumes 0.55 watt; one sq. mm. of carbon filament radiates 0.182 candle-power and requires 0.63 watt. Thus the tungsten filament consumes only 80 per cent of the power taken by an equal surface of the carbon filament, but gives 275 per cent of the light given by the carbon filament.

In a paper read by H. Hirst before the British Institution of Electrical Engineers, the author states that "if the kind of radiation were the same in both cases, the carbon filament ought to get hotter than the tungsten filament by about 60° C., because of the higher total radiation consumption per unit of surface. On the other hand, considering the greater light emanating from the tungsten filament, its temperature ought to exceed that of the carbon filament by about 200° C. These contradictory conclusions show clearly how different is the radiating power of the tungsten filament as compared with the carbon filament. The latter behaves more like the 'black body' of the radiation theory. Approximate calculations show

that the temperature of the tungsten filament is, when consuming 1.1 watts per candle-power, about 250° C. higher than that of a carbon filament taking 3.5 watts per candle-power. If a carbon filament were to be overrun to such an extent as to consume only 1.1 watts per candle-power, its temperature would have to be raised by 360° C. The favorable radiating properties of the tungsten filament, therefore, mean that its temperature is 100° lower than that of a carbon filament of the same specific consumption. If it were not possessed of this radiating property it would have to be operated at a consumption of 1.5 to 1.6 watts per candle-power, in order that it might have the same life it actually possesses at 1.1 watts per candle-power."

If one takes the resistance of carbon, tantalum, osmium, and tungsten filaments at ordinary temperatures the resistance at those temperatures, which in a vacuum correspond to 1.5 watts per candle, will be as follows: For a carbon filament 0.55 times the original; for tantalum, 5.70 times; for osmium 8.50 times; for tungsten, 11 times. Under normal conditions the light of a carbon filament lamp rises and falls with the 6.3 power, that of the tungsten filament with the 3.6 power, of the voltage.

THREE-VOLTAGE RATING OF MAZDA TUNGSTEN LAMPS *

The Mazda incandescent lamp, when operated at a specific consumption of 1.25 watts per candle, has proved itself far more economical than either carbon, Gem, or tantalum lamps at all costs of energy above a few cents per

* By courtesy of National Electric Light Association.

kw.-hour. There are some cases, however, in which the cost of energy per kw.-hour is very low, perhaps a small fraction of a cent. In such cases a cheaper and less efficient lamp may show greater economy in operating expense than the Mazda lamp operated at 1.25 watts per candle. The somewhat higher renewal expense of the latter lamp at this specific consumption may not be counterbalanced by even a great reduction in the amount of energy used where the charge is low. Since the Mazda incandescent lamp is inherently of higher efficiency and quality, the question of its economical application to any particular case depends merely upon its operation at the correct specific consumption. In the case just cited, a small sacrifice in efficiency of the Mazda lamp could be made in order to reduce the renewal expense and thus secure greater economy than could be obtained with the other types of lamps, even when using very cheap energy. Besides the actual saving in energy made possible through the use of the Mazda lamp, there is the very important possibility of releasing generating equipment, which, even where the operating cost is low, may often be of great value. This point should not be overlooked in deciding the relative economy of high-efficiency versus low-efficiency lamps.

The incandescent-lamp manufacturers have recently made a radical change in their methods of rating these lamps, in order that the lamps may be used with greater economy under those certain conditions where heretofore their cost of operating exceeded that of a less efficient type of lamp. The results of this change are most valuable in cases where the cost of electrical energy is low. The new method of rating, called the "three-voltage plan," is based on the fact that for any given set of conditions, depending

upon the cost of energy and cost of lamps, there is a certain specific consumption and life at which it is most economical to operate a given lamp. Each Mazda lamp is labelled with three voltages, two volts apart, as, for example, 114, 112, and 110, called "top," "middle," and "bottom" voltage, respectively, from their positions on the label.

This method of rating makes it possible for a customer to select the particular specific consumption he wishes to use, by specifying that either the top, middle, or bottom voltage, as the case may be, should be the same as that of his lighting circuits.

When used at the top voltage the Mazda lamp consumes the least energy for the light produced, and gives a life of 1,000 hours. At the middle voltage more energy is consumed per candle-power produced, and the life is lengthened (due to operation at a lower temperature) to 1,300 hours. At the bottom voltage the lamp is operated at the lowest efficiency and gives a life of 1,700 hours. It is obvious that the relative cost of lamp and energy will determine the most economical life and efficiency, since if energy is cheap the saving obtained by operating the lamp at high efficiency is not sufficient to counterbalance the resulting higher renewal expense. On the other hand, if energy is relatively expensive, then it will be desirable to operate the lamp at a high efficiency, since the saving in energy at the higher rate will more than pay for the increase in renewal expense.

The specific consumption of the different sizes of lamps at the top voltage is not the same, since the larger lamps are relatively longer-lived than the smaller ones, and, in order to give all sizes a uniform life of 1,000 hours at the top voltage, it was necessary to operate the 25-watt lamp at 1.33 watts per candle, the 40-watt lamp at 1.25, the 60-

TABLE I.—SHOWING TOTAL COST OF PRODUCING LIGHT WITH TUNGSTEN LAMPS AT TOP, MIDDLE, AND BOTTOM VOLTAGES, AT VARIOUS COSTS OF ENERGY

Nominal Watts	25			40			60			100			150			250		
Nominal Candle-Power	20			32			48			80			120			200		
Voltage	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Watts per candle	1.33	1.39	1.45	1.25	1.30	1.35	1.20	1.25	1.30	1.20	1.25	1.30	1.20	1.25	1.30	1.15	1.20	1.25
Actual Watts	25.0	24.2	23.3	40.0	38.9	37.8	60.0	58.0	56.5	100	98.0	94.2	150	145.5	141.2	250	242.5	235
Actual Candle-Power	18.8	17.4	16.1	32.0	29.9	28.0	50.0	46.5	43.5	83.3	77.6	72.4	125	116.4	108.6	217.3	202.0	188.0
Total Lumens	184.2	170.5	157.8	309.8	289.4	271.0	490.0	455.7	426.3	816.0	760.0	710.0	1225	1141	1064	2104	1954	1819
Lumens per Watt	7.36	7.05	6.77	7.74	7.44	7.17	8.16	7.86	7.54	8.16	7.76	7.54	8.17	7.84	7.54	8.41	8.05	7.74
Hours Life	1000	1300	1700	1000	1300	1700	1000	1300	1700	1000	1300	1700	1000	1300	1700	1000	1300	1700
Kw. H'rs per 1,000 H'rs	25.0	24.2	23.3	40.0	38.9	37.8	60.0	58.0	56.5	100	98.0	94.2	150	145.5	141.2	250	242.5	235
Cost of Frosted Lamp	$0.75	$0.75	$0.75	$0.85	$0.85	0.85	$1.17	$1.17	$1.17	$1.55	$1.55	$1.55	$2.25	$2.25	$2.25	$3.20	$3.20	$3.20
Lamp Renewals per 1,000 Hours	.75	.58	.44	.85	.65	.50	1.17	.90	.69	1.55	1.19	.91	2.25	1.73	1.32	3.20	2.46	1.88

COMBINED COST OF ENERGY AND LAMP RENEWALS PER 100,000 LUMEN-HOURS IN DOLLARS

Variable cost of energy. Cents per Kw. Hour																		
1	$0.54	$0.48	$0.43	$0.40	$0.36	$0.32	$0.36	$0.32	$0.29	$0.31	$0.29	$0.26	$0.31	$0.28	$0.26	$0.27	$0.25	$0.23
2	.68	.62	.57	.53	.49	.46	.48	.45	.43	.44	.41	.39	.43	.41	.39	.39	.37	.36
3	.81	.76	.72	.66	.66	.60	.61	.58	.56	.56	.54	.52	.55	.53	.52	.51	.50	.49
4	.95	.90	.87	.79	.76	.74	.73	.71	.69	.68	.67	.66	.67	.66	.65	.63	.62	.62
5	1.09	1.04	1.02	.92	.90	.88	.85	.83	.82	.80	.80	.79	.80	.79	.79	.76	.75	.75
6	1.22	1.18	1.17	1.05	1.03	1.02	.97	.96	.96	.93	.93	.92	.91	.92	.92	.86	.87	.88
8	1.49	1.47	1.46	1.31	1.30	1.30	1.22	1.22	1.22	1.17	1.19	1.19	1.16	1.17	1.19	1.10	1.12	1.14
10	1.75	1.75	1.76	1.57	1.57	1.58	1.46	1.47	1.49	1.42	1.45	1.46	1.41	1.43	1.45	1.34	1.36	1.40
12	2.03	2.04	2.05	1.82	1.84	1.86	1.71	1.72	1.75	1.66	1.70	1.72	1.65	1,68	1.72	1.58	1.62	1.65
16	2.57	2.59	2.64	2.34	2.37	2.42	2.20	2.23	2.28	2.15	2.22	2.25	2.14	2.19	2.25	2.05	2.11	2.17
20	3.12	3.16	3.28	2.86	2.91	2.97	2.69	2.74	2.81	2.64	2.73	2.78	2.63	2.70	2.88	2.53	2.61	2.69

Spherical Reduction Factor: 25, 60, 100, and 150-watt lamps = 78 per cent.
40 and 250-watt lamps = 77 per cent.

watt, 100-watt, and 150-watt lamps at 1.20, and the 250-watt lamp at 1.15 watts per candle.

The advantage of the new plan will be apparent by referring to Table I, accompanying, which shows the cost of producing light with Mazda lamps. This table is based on the list-price of bowl-frosted Mazdas (at the time of writing, June, 1910) and shows the total cost of operating the several sizes at top, middle, and bottom voltage with costs of energy from one cent to twenty cents per kw.-hour. The total cost given in the table includes the cost of the energy consumed and the renewal expense involved in the production of a quantity of light equivalent to 100,000 lumen-hours (which is equal to about 10,200 mean horizontal candle-hours in the case of the Mazda lamp).

The manner in which the most economical efficiency varies with the cost of energy is also shown in Table I, where we may take, for example, the cost of producing 100,000 lumen-hours with a 60-watt Mazda at top, middle, and bottom voltages, using energy at costs of from one cent to twenty cents per kw.-hour. With the 60-watt bowl-frosted Mazda lamp, and with energy at one cent per kw.-hour, a certain number of candle-hours can be produced most cheaply if the lamp is operated at the bottom voltage. The difference between the cost at top and bottom voltages, with energy at this rate, is about 19 per cent. With five-cent energy the bottom voltage is still the cheapest, but is now only about 3 per cent cheaper than at the top voltage. At eight cents per kw.-hour it is as economical to operate at the top and middle voltages as at the bottom voltage, and above eight cents the top voltage is the most economical. Where the per cent saving, which it is possible to obtain by operation at the bottom voltage, is slight, as, for example, in the case just considered with

energy above five cents per kw.-hour, it is far better to use the lamps at the top voltage and thus secure not only a better quality of light but also more light from a lamp of given size.

The greatest benefit can be derived from the three-voltage plan, however, at the low rates for energy. Operation at bottom voltage will then show economy for the Mazda lamps over either carbon, Gem, or tantalum, down to energy costs as low as 0.2 cent per kw.-hour.

Table II shows the comparative cost of producing 100,000 lumen-hours with carbon, Gem, tantalum, and Mazda lamps at costs of energy from 0.2 cent to one cent per kw.-hour. This table is based on conservative total-life values of the carbon and Gem lamps in place of the usual useful life, since practically all lamps are left in service until ultimately burned out, rather than only until they have dropped to 80 per cent of this initial candle-power. The Mazda lamps have all been computed at bottom voltage, and the Gem lamp has been treated in the same way, as this is the most economical voltage for such low costs of energy. The average values for candle-power and watts during the life periods shown have been taken in every case, rather than the initial values, because the Mazda lamp maintains its candle-power much better than the other types. This feature is a distinct advantage in its favor and should be considered in comparing it with other types of lamps. The costs of lamps taken in this table are those for clear lamps in standard package quantities.

For energy costs above five cents any percentage saving that it is possible to obtain by operating the Mazda lamps at other than the top voltage becomes so small as to be negligible in comparison with the better quality of light obtained at the higher voltage. Only in those cases where

TABLE II.—SHOWING COMPARATIVE COST OF 100,000 LUMEN-HOURS—CARBON, GEM, TANTALUM, AND TUNGSTEN LAMPS, WITH ENERGY BELOW 1 CENT PER K.W. HOUR

Rating		Carbon		Gem	Tantalum	Tungsten					
		16 C.P.	16 C.P.	20 C.P.	20 C.P.	25 W.	40 W.	60 W.	100 W.	150 W.	250 W.
		3.1 W.P.C.	3.5 W.P.C.	Bot. Voltage	2 W.P.C.—D.C.	Bottom Voltage					
Actual Initial Candle-Power		16	16	16.7	20	16.1	28.0	43.5	72.4	108.6	188.0
Actual Initial Watts		49.6	56	47.3	40.0	23.3	37.8	56.5	94.2	141.2	235.0
Nominal Watts per Candle		3.1	3.5	2.83	2.00	1.45	1.35	1.30	1.30	1.30	1.25
Hours Life		800	1700	1450	1200	1700	1700	1700	1700	1700	1700
Average Candle-Power During Life		13.20	13.06	14.00	21.66	16.46	28.30	42.60	71.50	107.2	179.7
Average Watts During Life		48.6	54.9	40.2	41.0	23.9	38.6	55.6	92.6	138.8	241.3
Reduction Factor		82.5	82.5	82.5	79.0	78	77	78	78	78	77
Lumens		138	135	145	215	161	274	417	701	1051	1739
Cost of Lamp, Standard Package		$0.18	$0.18	$0.225	$0.405	$0.567	$0.648	$0.891	$1.175	$1.701	$2.430
Cost of Energy, cents per K.W.H.	.2c.	$0.233	$0.160	$0.162	$0.195	$0.237	$0.167	$0.152	$0.125	$0.122	$0.110
	.3	.269	.200	.190	.214	.252	.181	.166	.138	.135	.124
	.4	.303	.241	.218	.233	.266	.196	.179	.151	.148	.138
	.5	.339	.282	.246	.253	.281	.210	.192	.165	.161	.152
	.6	.374	.323	.273	.272	.296	.224	.206	.178	.175	.166
	.8	.445	.404	.329	.310	.326	.252	.232	.204	.201	.103
	1.0	.515	.485	.384	.348	.355	.280	.259	.231	.207	.221

energy is very cheap should anything but the top voltage be seriously considered. For ordinary use on central-station circuits at the usual central-station rates the top voltage should always be used. The prime object of the three-voltage plan, as applied to Mazda lamps, was to widen the field of its commercial application by making it competitive with the cheaper and less efficient lamps on low cost of energy.

Higher Initial Brilliancy of Tungsten Lamps—Phenomena of "Overshooting."—The singular property of the tungsten lamp to "overshoot," or to give temporarily a higher initial than normal candle-power, was first discovered by Mr. John B. Taylor and is explainable in the following manner. The filament of the carbon incandescent lamp possesses a negative temperature coefficient; that is to say, a rise in voltage causes a more than corresponding rise in current, and when the lamp is connected to a source of constant potential the current starts at a comparatively small value and increases to a maximum when the lamp has attained full candle-power.

In the tungsten filament lamp the situation is just the reverse, since tungsten has a positive temperature coefficient, or, in other words, an increase in voltage increases the current in smaller proportion, and when the lamp is connected to a constant potential supply the current is a maximum when the lamp is cold and decreases to a final value when the lamp reaches full brilliancy. The most important difference between the two lamps, due to these different characteristics, is that while a tungsten lamp reaches full candle-power the instant the current is turned on it, a carbon incandescent lamp comes up to full candle-power only after a perceptible period of time.

The apparent temporary increase in the candle-power of a tungsten lamp was observed early after the lamp was invented, but it was generally ascribed to some possible physiological action due to the slow contraction of the pupil of the eye. This explanation, however, is unsatisfactory, for the reason that in the case of a rapidly moving railway train bringing the observer into the light of an incandescent lamp there is no "overshooting" effect.

The "overshooting" effect is most observable when the lamp is cold before closing the switch. On lighting a tungsten lamp again that has just been turned out, the overshooting effect is not apparent.

Taylor sought to demonstrate definitely whether such "overshooting" is of physical or physiological origin, his experiment being carried out as follows: The light from a tungsten lamp was caused to strike a moving photographic film, so that any variation or overshooting of the light would give a corresponding change in the opacity of the photographic film. This test was made by placing a film drum and holder of the standard General Electric oscillagraph and fitting them in a screw-cutting lathe. A piece of cardboard with one-eighth inch slit was fastened to the tool post, so that the travel of the latter carriage caused this slit to move across the slit in the film holder. In this way the velocity of the film and the cross travel of the slit were adjusted without the use of special apparatus.

The experiment demonstrates that for a period of perhaps one-tenth of a second, the light coming from the lamp is above normal by as much as 20 per cent; for instance, a tungsten lamp rated at 40 candle-power will give about 50 candle-power for an instant after being lighted.

Theories of "Overshooting" in Tungsten Lamps.—The

theory given by Taylor to account for this phenomenon is based on the fact that there is a small amount of residual gas in the lamp, which is attracted to the walls of the lamp when it is cold; and when the lamp is lighted and warms up, this residual gas is driven off, lowering the vacuum. With a high vacuum practically all the energy must be radiated from the filament; conversely, on a lowering of the vacuum, some of the heat is carried away by convection and conduction. When all the heat is carried away by radiation, the filament runs at a higher temperature and will give more light. Various other theories have been advanced to account for the temporary increase of candle-power in tungsten lamps when first lighted, but only two are of much consequence. One is that a cold tungsten filament lamp absorbs and occludes certain gaseous substances from the low-pressure space within the chamber. Owing to the presence of these gases the filament shines more brightly when first brought quickly to incandescence, but after the gases have been driven off by the heat, the extra luminescence disappears and can be regained only by prolonged cooling and rest.

The other theory is that the increase of resistance accompanying the rise of temperature takes a certain small interval of time to be established, so that, when the temperature is rising at the rate of tens of thousands of degrees per second, the resistance lags perceptibly. The resistance does not suppress the current as quickly as it should, and an extra rush of current and heat energy goes through the filament, raising the temperature above normal, with a corresponding increase in brilliancy. The first or the chemical theory seems to be the more probable explanation, but in the light of more evidence neither is satisfactory.

Effect of Voltage Variation on the Life of Incandescent Lamps.—It is not as highly essential to maintain a uniform voltage at the terminals of a tungsten lamp as upon the terminals of a carbon filament lamp. The effect of over-voltage on a tungsten lamp is not so serious a factor in reducing the useful life of the lamp as is the case with the carbon filament lamp; however, this should not be implied as meaning that the supplying voltage may be allowed to fluctuate within wide limits without injurious effect. The relation between actual life and useful life (the latter being defined as the number of hours within which the candle-power drops to 80 per cent of the original value), is quite different with carbon lamps and metallic filament lamps. When metallic filament lamps are operated at normal voltage the actual life is longer than the useful life. In other words, if a tungsten lamp is carefully handled, kept free from vibrations, and is operated at normal voltage, it will decrease in candle-power to 80 per cent of the original value after 1,800 hours of burning. Under average conditions of burning, however, the filament will break before that time, and if breakage occurs, for example, after 1,000 hours of burning, the candle-power will have dropped by only 7 per cent of the original value. If the working voltage is higher than normal, both the useful life and the actual life decrease, but the useful life falls off more quickly.

If the voltage is increased above the normal, the increase of power consumption should be proportional to the square of the voltage if the resistance of the filament remains constant. But since the resistance also increases, the energy the lamp takes increases less than the square of the voltage. This is obvious from the first three columns of the table appended, which gives the results of investi-

gations made by Herr H. Remane in a paper before the German Association of Electrical Engineers:

Per Cent. v	v²	w	r	cp	h	u l	cp-hours
100	100	100	100	100	74	1,800	100
105	110.1	108.5	101.3	121.5	27.6	900	61
110	121.0	117.0	103.4	143.0	13.8	370	26
115	132.2	125.3	105.5	167.0	8.0	210	15
120	144.0	132.2	108.0	193.5	5.4	125	9
125	156.3	142.7	109.6	221.0	2.9	70	5

The figures in the first column refer to the voltage at the terminals of the lamp in per cents of normal voltage. The second column gives the square of the voltage in per cent. The third column gives the watts consumed by the filament in per cent. It will be noted that if the voltage is raised 5 per cent above normal, the square of the voltage is raised 10.1 per cent above normal, but the watts consumed are increased only 8.5 per cent above normal. The fourth column, r, gives the resistance of the hot filament in per cents of the hot-filament resistance at normal voltage. Whenever there is an instantaneous rise of the voltage above normal, the candle-power is instantaneously raised also considerably above normal. A rise in voltage of 25 per cent on the lamp produces an increase of candle-power to more than double the normal. This increase of candle-power, however, is of brief duration. The mean results of a large number of tests made by Herr Remane are shown in the curves of Fig. 11. Some of the lamps were tested at normal voltage, some at 5 per cent above rated voltage, and so on. It will be seen that all of the curves are of the same general order. The candle-power first increases above normal, attains a maximum and then decreases, the decrease being the more rapid the greater the increase of voltage above normal. The num-

ber of hours in which the candle-power decreases one per cent is found from the final parts of the curves, in which the falling off of candle-power with respect to time is represented by straight lines. The column marked h gives these figures. The useful life for the different curves is indicated by the letter h (referring to hours). The same figures are given in the table as u l (useful life). The column marked candle-power hours gives the actual candle-power hours during useful life. The effect of voltage increase on the total candle-power hours of a

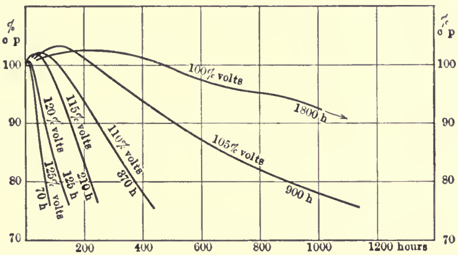


FIG. 11.—Characteristic Curves of Tungsten Lamps.

metallic filament lamp is strikingly shown by the table; for instance, a rise of 10 per cent in voltage increases the candle-power by 43 per cent, but the total candle-power hours during useful life are reduced to one-fourth of the value at normal voltage.

A recent issue of the *Minnesota Engineer*, published at the University of Minnesota, contains an article by Mr. A. J. Hitzker giving some interesting data relating to the characteristics of carbon and metallic filament lamps.

The accompanying table shows the resistances of the several types of filaments when at room temperature and when in active service; these lamps are for electromotive forces of from 100 volts to 120 volts. It will be noted that

the resistance of a carbon filament decreases by 50 per cent, that of a tantalum increases by 400 per cent, and that of a

Type of Lamp	Rating, Watts	Resistance in Ohms	
		Cold	Hot
Carbon, 19 cp	59	430	214
Carbon, 38 cp	118	222	105
Tantalum	40	60	315
Tantalum	80	30	160
Tungsten	25	35	450
Tungsten	40	30	353
Tungsten	60	23	215
Tungsten	100	12	130
Tungsten	250	5	54

tungsten increases by 1,600 per cent when heated from room temperature to the operating temperature. In Figs. 12, 13, and 14 variations in resistance are shown for changes in candle-power from 70 per cent to 150 per cent of normal, while an indication of the changes that must be made in the electromotive force impressed upon each filament, in order to produce the variations indicated, is also given in Figs. 12, 13, and 14.

In Fig. 15 are given curves showing the variation in candle-power of carbon, tungsten, and tantalum lamps throughout their life up to 1,000 hours. The curves relate to a 16-cp. carbon lamp consuming 3.5 watts per candle, a 19-cp. carbon lamp consuming 3.1 watts, a 20-cp. graphitized-carbon lamp consuming 2.5 watts, a 20-cp. tantalum lamp consuming 2 watts, and a tungsten lamp consuming 1.25 watts per candle. It will be noted that throughout its whole life of 600 hours at a frequency of 60 cycles, the tantalum lamp operated at a candle-

power above its initial rated value. The tungsten lamp maintained its initial candle-power for 650 hours, and even at 1,000 hours it gave 94 per cent of its rated output. The greatest decrease in candle-power was shown by the Gem graphitized carbon-filament lamp, which maintained its initial candle-power for only 75 hours, and at the end of

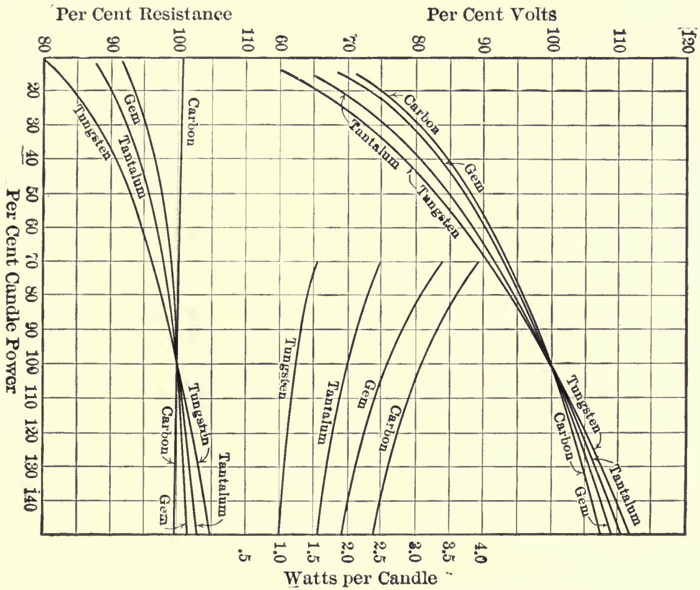


FIG. 12.—Variations in Resistance of Various Lamps.

1,000 hours gave only 66 per cent of its rated candle-power.

Difficulties in the Manufacture of "High-Voltage" Tungsten Lamps.—The specific resistance of tungsten being so low, it is obvious that the length of filament required for voltages above 110 becomes unduly great, so as to offer great difficulties in manufacture. Inventors have endeav-

ored to overcome this difficulty by additions to the pure metal to increase the specific resistance. A process of this kind has been developed by the Watt Company (Eng-

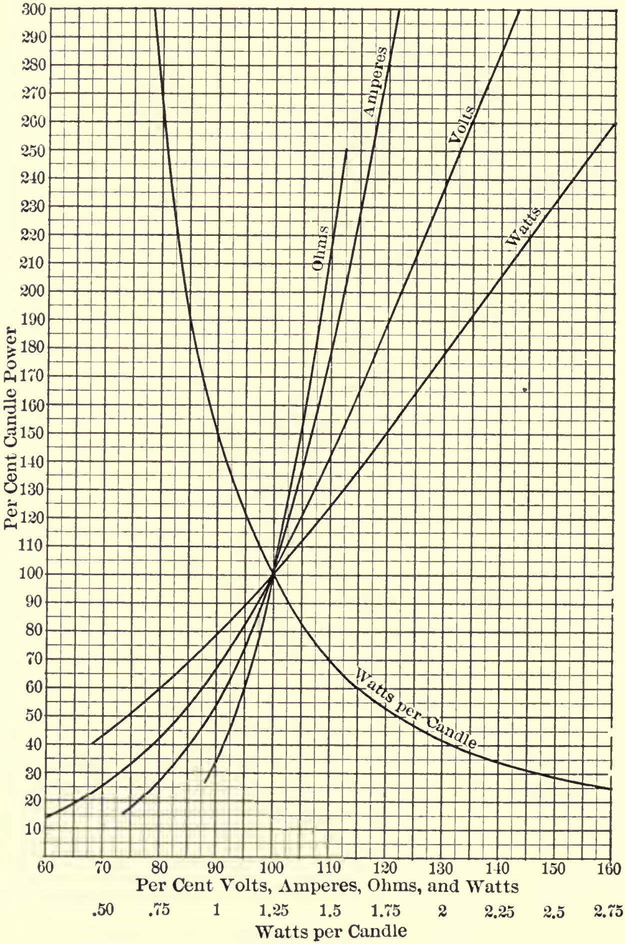


Fig. 13.—Curves Showing per cent Change of Resistance and Candle-power of Tungsten Lamps at Different Temperatures.

land), in which filaments are made from a tungsten alloy with titanium or thorium or vanadium. In this process finely comminuted tungsten well powdered is intimately

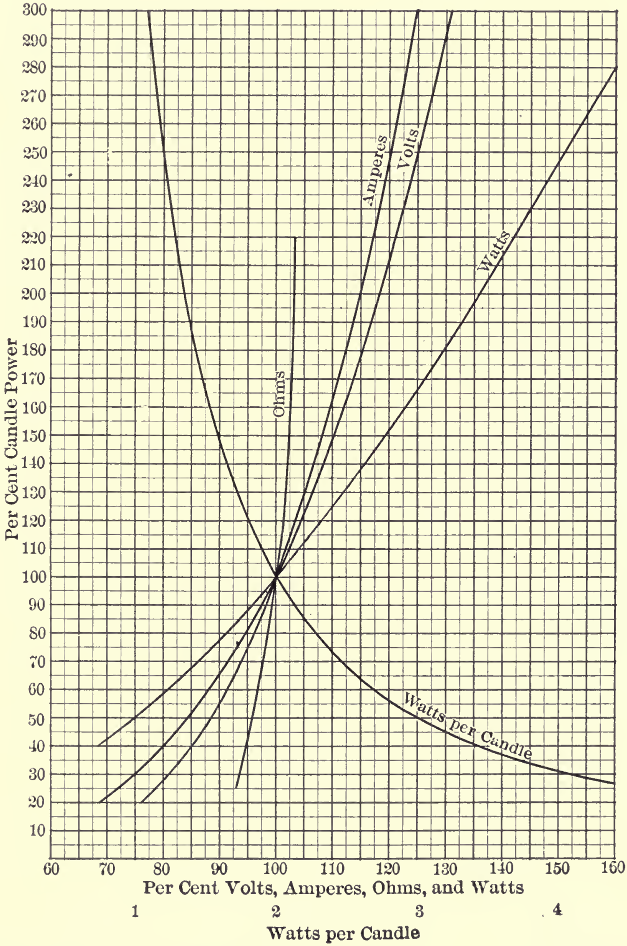


FIG. 14.—Curves of Changes of Resistance and Candle-power of Tantalum Lamps at Different Temperatures.

…h powdered oxides of the above metals, and a …agent containing carbon. Only just sufficient …al is added to the filament to render the cold raw … a conductor. After forming the paste made into fil… , the filaments are treated in a chamber from which air is excluded. This treatment is followed by the heating of the filaments to white heat in an atmosphere of hydrogen. The reducing agents for the oxides are carbon in the bind-

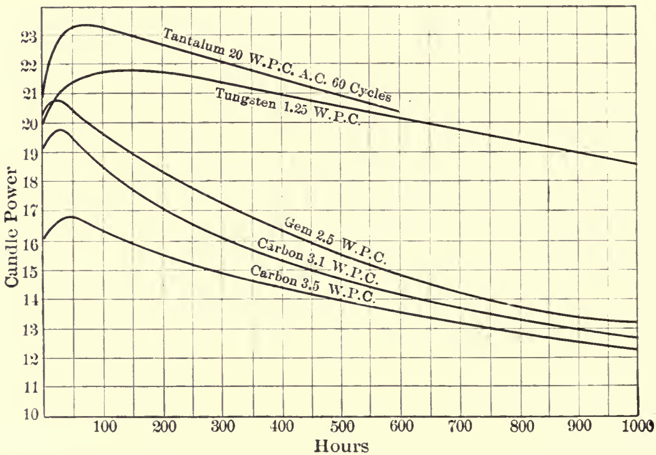


FIG. 15.—Variation in Candle-power in Various Kinds of Lamps.

ing material and the hydrogen and an alloy of tungsten, the metals resulting from the oxides by chemical reduction. The virtue of such an alloy, as, for example, tungsten with thorium or titanium, lies in the fact that it has a high melting point and a much higher specific resistance than pure tungsten.

The Union Lamp Company (England) uses a process which accomplishes the same result but in an entirely different way. The final filament is either of tungsten

or molybdenum or an alloy of these two metals with silver. The introduction of a small percentage of silver in the filament is said to increase the specific resistance and also to decrease the brittleness of tungsten. In their process carbon filaments are heated to a temperature of 600° C. by passing electricity through them, and simultaneously exposing them to the action of the vapors of salts of tungsten or molybdenum, such as the chlorides, which readily evaporate in a vacuum. Hydrogen is introduced at the same time and the metals are deposited on the carbon filaments, the chloride combining with the hydrogen. Silver is introduced in the filament either by previously treating the carbon filaments with a solution of a silver salt, or at the same time by adding silver chloride along with the tungsten and molybdenum chlorides. It is thus easy to burn the carbon out of the finished filament by raising the whole to a high temperature in an atmosphere of hydrogen.

The fragility of the tungsten filament has been so far the chief drawback to the new lamp, but there is evidence of material improvement in this particular. The lamps can now be supplied without much trouble and can be distributed with very small breakage. In a shipment of 75,000 the General Electric Company reports a breakage of less than 1.5 per cent, which is indeed remarkable considering the extreme fragility of the first tungsten filaments. But when the lamps are put in the hands of the user trouble begins. It is a very singular fact that the fragile filaments will at times endure abuse, and at still other times an almost imperceptible jar will fracture them. Sometimes merely overhead vibration, a rough handling of the key socket, or a tap on the shade may break the filament. Hence one cannot exercise too much

care in handling or cleaning metal filament lamps. However, considering all the chances of breakage, the life of the new lamps is remarkable.

The introduction of the 25-watt lamp, while of great importance in leading to better economy, is very likely to lead to more temporary difficulty from breaks. The filaments of these small lamps are exceedingly slender, and, while of long life in the matter of burning, cannot stand the shocks of thicker filaments. In an admirable editorial entitled "The Tungsten Lamp Situation," *The Electrical World* of Jan. 2, 1909, thus speaks of the caution to be observed with the smaller candle-power metal filament lamps: "A word of warning seems to be in order about the 25-watt tungsten lamp. It is certainly a most handy size and one that is bound to be popular, but it must be dealt with rather cautiously. It is somewhat more fragile than others of its kind and, while it gives excellent life if let alone, it will not generally stand rough treatment. If there is need to clean the shade the lamp should first be lighted and current kept on until cleaning is done. It is of just about the size of the ordinary 16-candle-power lamp and unluckily, therefore, fits the old 16-candle-power fixtures and shades. The larger part of the 16-candle-power fixtures have the lamps pointing downward at an angle and so located that the lamp is in pretty plain view. Now, with a carbon filament this is bad enough, but it easy to get frosted lamps and so reduce the intrinsic brilliancy to reasonable limits. Up to the present there has been difficulty in getting frosted 25-cp. tungsten lamps, so that the size which really goes into the most exposed places is commonly bare and, with its enormous filament brightness, is always ready for mischief. There ought to be a special effort on the part

of manufacturers to put out frosted lamps, which are the only ones suitable for use in a large proportion of existing fixtures.

"As to the general properties of the present crop of tungsten lamps they are reasonably satisfactory. Much care is being taken with the anchoring, so that it is practicable to burn most of the sizes, perhaps all, out of the perpendicular without any specially bad results—indeed, in most cases, with impunity. The commonest fault is blackening, which now and then is very troublesome. When a tungsten lamp does blacken, it usually makes a thorough job of it in rather short order. As the manufacturer shifts more and more to tungsten, this trouble from blackening will likely be reduced, but until it is there will be plenty of wrathful users bemoaning dim lamps to be replaced at a dollar or so each. The average working life, barring blackening, seems to be lengthening, and the ordinary claims of 800 to 1,000 hours of life is well substantiated. It is quite likely that, by a rather small sacrifice of efficiency, this life might be very considerably increased, and, indeed, it yet remains to be shown what the most economical efficiency really is.'' . . .

Proper Installation and Shading of Metallic Filament Lamps.—A frequent practice in installing ordinary carbon lamps with clear glass bulbs and without diffusing shades, is to place them directly in the line of vision. Such practice with the new lamps of high intrinsic brilliancy is extremely dangerous, as the money saved in light bills must be spent with the oculist if this precaution is disregarded.

Metallic filament lamps should be installed well above the line of vision, or else be so shaded that their intrinsic brilliancy will be considerably reduced. Satisfactory

results from such lamps can be obtained only by one or the other methods. The proper kind of shades for metallic filament lamps is also important. The use of unsuitable fixtures for the new lamp will destroy nearly all of their improved illumination. The 40- and 100-watt tungsten lamps are frequently stuck in shades that merely form a fringe around the socket or in shades in which they are entirely swallowed up. They are also burned in every conceivable position which is dangerous to the life of the filament as explained.

The coming of 18- and 25-watt tungsten lamps demands additional precaution in burning and shading them properly. The situation with respect to smaller-wattage lamps is thus tersely stated by *The Electrical World* in its issue of Nov. 7, 1908: "Now the 25-watt lamp is in even a much worse case because it is openly and evidently a substitute for the common 16-candle-power lamp, is of practically the same dimensions, and is simply substituted for it lamp for lamp. Hence the 25-watt tungsten lamp will be thrust, regardless of propriety, into any socket where a lamp has found lodgment. It will be expected to do service in big shades, little shades, and with no shade at all. It will be burned right side up and wrong side up and in all the directions between, used nakedly glaring into the user's face and hid behind so called 'artistic' shades that call to mind the scriptural suggestion of hiding a light under a bushel. . . . Wherever a man has had a 50-watt carbon lamp he will thriftily thrust in a 25-watt tungsten, and then will raise a howl of protest if it goes wrong. The 25-watt lamp is up against the stern realities of misuse to an extent incomparably greater than in the case of its larger predecessors."

The principal objections which are raised against the tungsten lamp are its fragility and high cost. These points are not without truth, although it is almost certain that improvements will in time eliminate both of these objections. The fragility of the lamp is not of serious consequence provided reasonable care is exercised in handling it.

The problem of burning the lamp in other than a vertical position is somewhat more serious, although some manufacturers claim that their lamps may be burned in any position. The result from burning recent types (1910) of tungsten lamps, especially the 40- and 60-watt sizes, in various positions proved to the author that properly made tungsten lamps can be burned in almost any position, provided the angle with the vertical does not exceed about 45 degrees.

Low-Voltage Tungsten Lamps.—Two inherent deficiencies of tungsten lamps for voltages of 110 and upward, have tended to retard their substitution for carbon lamps, aside from the question of the relatively high cost of metallic filament lamps: (1) they cannot as yet be constructed in units smaller than 20-candle; and (2) their filaments, particularly in the smaller sizes, are rather fragile.

Certain conditions of illumination—such as sign and decorative lighting—require lamps of smaller candle-power than the high-voltage lamps referred to above; and the metal filament lamps, to compete with the less expensive carbon lamp in such service, must possess important compensating advantages.

A number of tungsten lamp-makers have developed low-voltage lamps for operation on 110- to 220-volt alternating-current circuits through the medium of economy

coils. The economy coil is simply an auto-transformer which reduces the pressure of the supply circuit from 30 to 10 volts or any desired intermediate value. The saving effected by substituting economy coils and low-voltage lamps for an equivalent number of carbon lamps of equal candle-power may amount to as much as 50 per cent, in addition to the advantage of longer and better quality of illumination. The efficiency of the highest grades of low-voltage tungsten lamps is fully equal to that of the higher-voltage lamps, and they also have an average useful life of 1,800 hours or over.

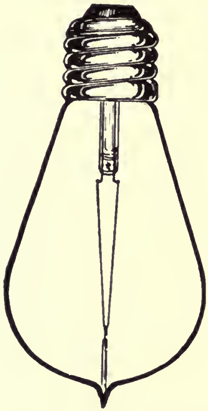


FIG. 16.—Hair-pin Shape Tungsten Sign Lamp.

Low-voltage tungsten sign lamps are made for wattages of from 5 (4 candle-power) to 10 (8 candle-power) and for a variety of voltages. Fig. 16 shows a 5-watt, 10-volt sign lamp with hairpin loop filament, the horizontal illumination of which is 4 candle-power and the end-on illumination about one candle-power. A sign lamp of the same capacity, etc., but having a W-shaped filament and giving an end-on illumination of 4-candle-power is shown in Fig. 17. A sign lamp with V-shaped filament is shown in Fig. 18.

The use of 4 candle-power tungsten sign lamps will give a saving in energy over carbon lamps of almost 70 per cent, since the small candle-power carbon lamp has a much higher watt consumption per candle-power than the usual size lamp.

Two methods have been developed for utilizing 10-volt

tungsten lamps for sign lighting. The first method, which is adapted for use with already installed signs without change of wiring, consists of a two-circuit transformer having a primary wound for 110- or 220-volt circuits, and two secondary 10-volt circuits. The two secondary circuits may be connected in multiple for two-wire lighting, or they may be connected in series for three-wire lighting and the neutral wire brought out from the series connection of the secondary coils. The primary winding is provided with three taps, giving three primary voltages, such as 100, 110, and 120 volts, or 200, 220, and 240 volts.

FIG. 17.—W-Shape Tungsten Sign Lamp.

The second method for employing 10-volt lamps for sign lighting is also by the use of an auto-transformer economy coil, but has 12 10-volt circuits as shown in the development of the secondary winding, Fig. 19. Three taps are led out from one end of the winding to permit the use of the coil on 100-, 110- or 120-volt circuits. This type of economy coil is of lower first cost than the transformer type and its use gives greater economy when the lamps in a sign are divided in a suitable number of circuits. Any number of the circuits of the second type of coil may be used and

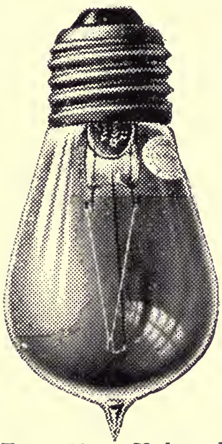


FIG. 18. — V-shaped Filament Sign Lamp.

the others left idle, but, when so operated, the coil losses are greater.

Economy coils for sign lighting are usually of the air-cooled type, and are provided with weather-proof covers for outdoor mounting.

The Adapter Transformer for Use with Tungsten Incandescent Lamps.—The use of the low-voltage and low-candle-power tungsten lamps described on pages 63 and 64 on higher-voltage circuits requires in connection with them the employment of a small transformer to reduce the supply voltage. The appearance of a type of "adapter transformer" when fitted to an incandescent lamp is

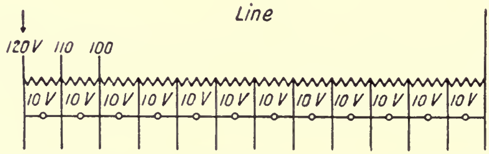


FIG. 19.—Secondary of Tungsten Economy Coil for Sign Lamp.

shown in Fig. 20. As can be seen, the transformer is connected between the lamp and the switch so that its use does not require any change of the wiring of the room. The transformer is mounted in the lamp socket like any ordinary lamp, and the low-voltage lamp is screwed in a socket fitted at the lower end of the transformer. A sectional view of the construction of the transformer is shown in Fig. 21. A single-core iron strip is insulated and first the primary and then the secondary winding are put on. The ends of the strips are then bent round at both ends and both sides to form a closed magnetic circuit. The rating of the adapter transformer shown for continuous use is 20 watts and the usual arrangement is to use one transformer in conjunction with one 16-candle-

power, 25-volt lamp or two 10-candle-power 25-volt lamps. Such transformers are made for primary voltages of from 100 to 250 volts, and for secondary pressures of from 25 to 50 volts, and for any required frequency. Since the usual carbon filament lamp consumes 3.5 watts per candle initially, while most metallic filament lamps take only 1.2 watts per candle and the efficiency of the adapter trans-

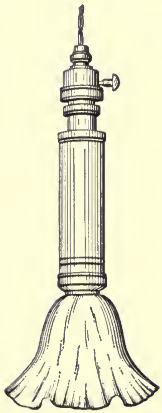


Fig. 20.—A Type of Adapter Transformer in Position.

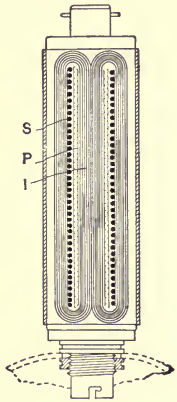


Fig. 21.—Sectional View of Transformer.

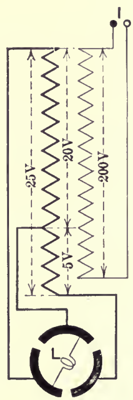


Fig. 22.—Adapter Device of "Turn" Type.

former is 85 per cent, the energy consumption of the combined lamp and transformer is less than 1.5 watts per candle, or less than one-half that of the carbon filament lamp.

Some types of adapter lamp transformers are fitted with "turn" devices. By twisting the lamp socket the lamp terminals are brought in contact with stationary contacts connected to different points on the secondary winding as shown in Fig. 22. These three positions correspond to full candle-power, 10-candle-power, and 5 volts candle-power.

Types of Construction Used in Transformers for Metallic Filament Lamps.—There are two different arrangements of the secondary circuit of transformers used for reducing the voltage applied to metallic filament lamps. The transformer of the "balanced" type is, on account of advantages mentioned later, more commonly used. The difference in these two connections is apparently slight, consisting in the omission of a second low-tension circuit across the points, rendering it the "simple" type. The difference in their connections, however, has a marked effect on the rating of the transformer, because the utilization of the second low-tension circuit increases the total load that can be safely carried by nearly 600 per cent.

The "balanced" type transformer is superior to the "simple" type, both in efficiency and cost of installation, because the total losses are only those due to the full load of the transformer when the total load supplied is six or seven times the latter. The lower cost of installation is due to the fact that the "balanced" transformer must only deal with the out-of-balance current. The efficiency of a "balanced" auto-transformer is commonly as high as 99 per cent, while the efficiency of the "simple" auto-transformer rarely exceeds 98 per cent.

Devices to Absorb Shocks to Tungsten Lamps.—The sensitiveness of tungsten filaments to shocks and the consequent danger of breakage of filaments therefrom has resulted in the employment of "tungsten life-savers" and "anti-vibrators" as a protection against such accidents.

A type of shock absorber for use on clusters or multiple light fixtures is shown in Fig. 23. It consists of a sensitive helically coiled spring with a threaded bushing, into which the upper end of the rod supporting the fixture is screwed,

the weight of fixture, lamps, etc., being carried by it. The arrangement of the parts is such as to admit of a free lateral or oscillatory movement within a limited area. The device is made in suitable sizes or strengths to suspend fixtures weighing from 4 to 15 pounds, or more. It is designed for use on any standard fixture and when used in stores or offices may be entirely concealed by ceiling canopy. This type of "Tungsten Life-saver," as it is called, is attached to the ceiling by means of an ordinary crowfoot, and in steel buildings by an insulating joint. The appearance of a shop-cluster equipped with another "Tungsten Life-saver" can be seen in Fig. 25.

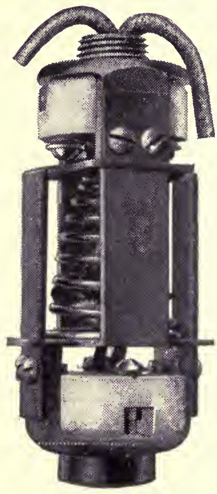


Fig. 23. — Tungsten "Life-saver."

A form of "jar absorber" for metallic filament lamps largely used in industrial plants is illustrated in Fig. 24. It consists of a spiral spring whose internal diameter is sufficient to allow it to slip over the conduit stem into which it is to be fitted. The spring is held on the conduit with flexible cotters, several of the last turns at each end being soldered together. The spring may be made of either steel or brass wire, the latter being preferable because it will not corrode. The spring cotters should be of brass or of brass wire. Steel cotters are dangerous to use, since they rust out rapidly, are difficult to remove, and if exposed to acid fumes are liable to rust entirely in two.

In selecting a diameter of wire from which to wind a spring to support a cluster of given weight, tables in re-

liable mechanical pocket books will be found of assistance. The strength of brass springs is only about one-third that of steel springs. The spring should be wound from the smallest wire that will safely support the load and enough turns should be used to prevent any shocks from reaching the tungsten lamps. The determination of the correct number of turns is largely a matter of experience, but from 20 to 25 is sufficient in most cases. The illustration (Fig. 24) shows the form the spring will assume under load. This "home-made" form of jar absorber is shown (in Fig. 25) applied to a four-lamp cluster.

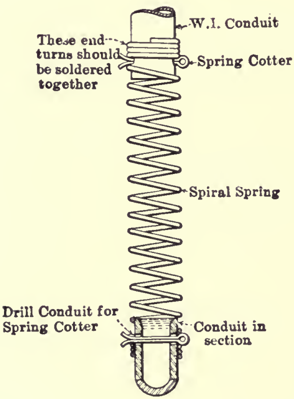


Fig. 24.—A Type of Tungsten Lamp Shock Absorber.

Another type of protector is the Just-Tungsten shock absorber. The absorber is not radically different from the types already discussed, consisting of the addition of a spring device to protect the lamps against shocks in the horizontal plane. It consists of an inner brass tube with a thread in the lower end. A spring surrounds the tube and the lower part contains the tube and spring. The upper part is connected with the fixture, and the wire is run through the protector and connected with the lamp socket. The latter is connected with the thread, and when equipped with lamp and shade the flange in the upper end pulls down the surrounding spring, and holds the load in an elastic swinging state, thus giving the lamp the necessary protection.

This form of absorber is claimed to protect the lamp

against both horizontal and vertical vibrations, and is installed between the fixture and the socket.

Analysis of Cost of Operation of Tungsten and of Carbon Lamps.—On account of the relative scarcity of tungsten ores, the high tariff on the importation of such ores under the new Payne-Aldrich tariff bill, the tedious and complex processes of manufacture, the initial cost of the tungsten lamp is considerably more than that of the carbon lamp.

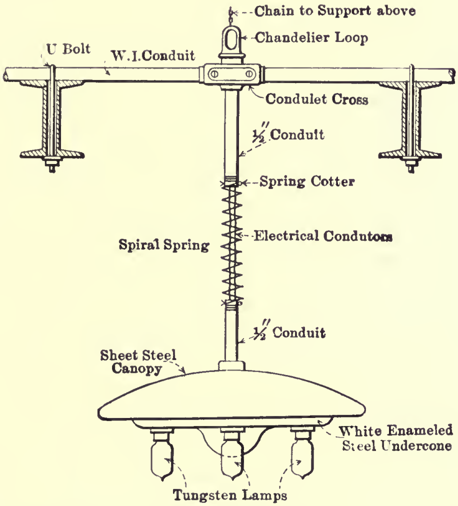


FIG. 25.—Lamp Cluster Fitted with Shock Absorber as Shown in Fig. 24.

This high first cost is, however, more than compensated for by the longer life and the superior efficiency of the tungsten lamp.

As an example of the economy of the tungsten lamp over the carbon lamp we will take a 40-watt (32-candle-power) tungsten lamp and a 32-candle-power carbon lamp, and compute the total cost of each of these lamps when

burned the same number of hours at the same price per kilowatt hour.

The high-efficiency carbon lamp has an efficiency of 3.1 watts per candle-power, hence the total wattage of the 32-candle-power lamp is 99.2. Its guaranteed life is 430 hours, making its total energy consumption $430 \times 99.2 = 41,156$ watt hours, or 41.15 kilowatt hours during its useful life. With energy at 10 cents per kilowatt hour, its cost of operation is $41.15 \times 10 = \$4.11$, to which should be added the first cost of the lamp, 30 cents, making its total cost $4.41.

The 40-watt tungsten lamp has a life of 800 hours, producing a total energy consumption during its useful life of $40 \times 800 = 32,000$ watt hours or 32 kilowatt hours. With energy at 10 cents per kilowatt hour, its cost of operation is $10 \times 32 = \$3.20$, to which the cost of the lamp, $1.10, should be added, making its total cost $4.30.

The total cost of operation of the carbon lamp for 800 hours' service is $\$4.41 \div 430 \times 800 = \$12.52$; while that of the tungsten lamp is $4.30, or a saving of $8.22, effected by the tungsten lamp.

A more significant appreciation of the economy of tungsten lamps may be obtained by a study of the reduction in the expense of lighting a small factory employing 75 25-watt tungsten lamps, to replace the same number of 16-candle-power carbon lamps; the lamps being in service 27 days in the month, for four hours per day. The service per month would thus be 108 hours. The initial cost of the tungsten lamps at 85 cents per lamp would be $75 \times .85$, or $63.75, for a life of 800 hours. Seventy-five 25-watt lamps have a total wattage of 1,875, and for 108 hours consume $1,875 \times 108 \div 1,000 = 225$ kilowatt hours. The cost for energy at 10 cents per kilowatt hour is $.10 \times 225 = \$22.50$. As the

proportion of the cost of the tungsten lamp is \$8.60 for 108 hours service, the total monthly cost of lighting is \$22.50 + \$8.60 = \$31.10.

The initial cost of 75 16-candle-power lamps at 20 cents is \$15.00, on a guaranteed life of 400 hours. For 108 hours service their cost would be \$4.05. Their total wattage at 50 watts each would be $50 \times 75 = 3{,}750$ watts, and the monthly consumption of the lamps 450 kilowatt hours. Their cost of operation at 10 cents per kilowatt hour would be $.10 \times 450 =$ \$45.00, to which the first cost for 108 hours, \$4.05 must be added, making a total monthly cost of \$45.00 + 4.05 = \$49.05.

Therefore, the total monthly saving effected by substituting 75 25-watt tungsten lamps for an equal number of 16-candle-power carbon lamps is \$17.95, while the illuminating efficiency of the tungsten lamp equipment is 20 per cent better. Even if the carbon lamps were *supplied free* by the lighting company, there would still be a saving in using tungsten lamps at their high first cost. The question of first cost is hence not a factor in considering the tungsten lamp.

Commercial Effect of the Introduction of the Tungsten Lamp.—In determining the commercial effect of the introduction of the tungsten lamp, the existing, as well as the possible, users of electric light may be divided into three classes, depending on their probable relations to this new illuminant. The first class comprises customers who are now using electric lighting at what may be called the "maximum point," measured by the present standards of illumination, thus reducing their watt capacity and hence decreasing the revenue of the central station.

The following concrete examples may be mentioned of class one. In New York City the large retail tobacconists,

the United Cigar Stores Company, has, from its inception, appreciated the tremendous advertising value of brilliantly lighted stores. Their recognition of electricity as the most efficient means to this end caused them to expend $80,000 in the year 1907 for the electric lighting of their stores in Manhattan Borough alone. By employing the tungsten lamp they decrease this expense by almost one-half, without sacrificing in the slightest their present high standard of illumination.

In the second class are also present customers, but their utilization of current for lighting is below the maximum or "saturation point," based on the present standard of illumination. Users of electric light in class two limit their amount of illumination chiefly on account of the expense involved. Central station officials are now debating whether this class of customers will employ the tungsten lamp for the purpose of obtaining the same illumination for less money, or to obtain a greater amount of illumination for the same cost. Thus far the latter alternative seems the more popular.

The more progressive of central station officials are engaged in an active campaign among this class of customers, pointing out the advantages which will be obtained from a greater amount of illumination, with a cheaper source of light. The recent appearance of multiple tungsten lamps of small candle-power (20 candle-power on 25 watts) will undoubtedly prove a powerful factor in popularizing metallic filament lamps for domestic or residence lighting.

In the third class of electric light users are those who are at present utilizing for economy's sake some means of obtaining illumination other than electricity. It is obvious that the deficit from the loss of customers in classes one and two must be regained from class three, and at this

writing the outlook augurs for not only a complete recovery of such loss, but also for a powerful impetus to the electric lighting industry, due to the fact it is now able to secure a class of customers hitherto unobtainable.

As a means of obtaining these possible customers of class three, The New York Edison Company has adopted a unique plan. A proposal is made to the users of this type of illuminant whereby the company arranges for the wiring and for the installation of a tungsten lamp fixture. The customer is permitted to select his own fixture from a number of designs covering a wide range in price, and the installation is made under the customer's direction. The entire cost of the wiring, the fixtures, and the tungsten lamps will be assumed by the company, but this amount must be repaid by the customer, without interest, in twelve consecutive monthly payments, which are added to the monthly bills for current. Upon the final payment, the entire equipment excepting the lamps, which are to be returned after burning out, becomes the property of the customer. If the customer vacates the premises before the final instalment is paid, or if the contract should be annulled before the final payment, it is agreed that the installation may be transferred to the successor under a similar arrangement, to continue until all payments have been made. If conditions prevent any such arrangement, the original customer must pay the full amount necessary for a complete liquidation.

Factors Which Have Retarded the Rapid Introduction of Metallic Filament Lamps.—The question which suggests itself to one after the discussion of the high efficiency and high intrinsic brilliancy of metallic filament lamps is, why, if such lamps possess superior features to all types of incandescent lamps yet produced, has their introduction in

this country been relatively slow? The chief factor which has retarded the rapid adoption of the new lamps is the fact that American central station customers are accustomed, in the majority of cases, to having their lamps supplied free. The relatively high cost of metallic filament lamps requires a renewal charge which imposes a kind of inertia to their progress, and until the public appreciates the necessity of the central station in putting the new lamps on a different renewal basis from the carbon lamp, the metallic filament lamp must struggle against this condition.

As is obvious, the new lamps must be advertised and the customers canvassed more thoroughly than is necessary where the consumer is in the habit of paying for his lamps, and hence more readily adopts and buys a new type of lamp instead of expecting the central station to supply him with lamps gratis.

The present state of the metallic filament lamp art and the existing commercial conditions with respect to the free renewal of incandescent lamps makes it difficult to determine the most satisfactory and desirable method of supplying tungsten lamps, but the consensus of opinion among central station men would seem to indicate that the central station gets the most desirable results by supplying the lamps on a monthly maintenance basis. It is left to the option of customers of either buying their lamps outright and assuming the risk of their breakage or, for a monthly charge, the central station will undertake the supply and care of the lamps.

A fertile cause of the slowness (relative) with which the tungsten lamp has been introduced has been the necessity in most instances of changing the installation to suit the tungsten lamp, which, in the units thus far supplied, gives

its best results when hanging in a pendant position with a single "Holophane" type reflector or enclosing globe around the lamp. Under many conditions this necessitates a rearrangement of installations, requiring, as a rule, the buying of new fixtures and changes in the location of lamps, which things the customer strenuously objects to. Therefore, the employment of metallic filament lamps is under most conditions a good deal more than the substitution of one kind of lamp for another, as it necessitates such changes as new shades of fixtures, or a new layout of the lighting in a scientific manner.

The tungsten lamp situation is thus a mooted problem. In an editorial under the title of "New Lamps and Renewal Rates," *The Electrical World* of May 2, 1908, thus splendidly philosophizes on the intricacies of the question: "One of the exasperating problems confronting the central station manager to-day is the proper method of dealing with the new high-efficiency lamps where free renewals have been the practice. The 100-watt tungsten lamps are now coming into fairly common use; 60- and 40-watt lamps are in production and seen occasionally, and even 25-watt lamps of foreign manufacture are making their way into service. In the long run, as in the case of every other improvement, increased efficiency will mean more business and more profits, but during the formative period of high-efficiency lamp practice, the ordinary system of charging leads to rather troublesome situations. The fundamental trouble is the present very high first cost of the lamps—in this country—$1.25 to $2.00, according to size, make, and discounts. Of course, candle-power to candle-power, the new lamps are cheaper sources of light than the old, including renewals, in the ratio of more than two to one at ordinary prices of current. The consumer

actually wins out on any customary method of charging, but in a territory where free renewals have been the rule, he dislikes to assume the renewals, even though he gains thereby, and especially if some of the lamps are, as is inevitable, of considerably shorter life than the average.

"Tungsten lamps, worked even at 1.25 watts per candle, are upon the whole very long-lived. Tests abroad have indicated a life four or five times greater than that of the carbon filament lamp, and at present 1,000 hours is not an unreasonable expectation of life before dropping 20 per cent in candle-power, although manufacturers are slow in guarantees of so much. But it not infrequently happens that individual lamps break or blacken at a few hundred hours and demand costly renewals, to the customer's sorrow, if he supplies his own lamps. What should be the policy of the central station in dealing with this matter? Can it afford to go in at the present time for actual free renewals, or should it guarantee renewals for a fixed charge, or a corresponding additional charge for current? On the face of returns, the free-renewal system is a considerable burden, equivalent not only to giving the consumer much cheaper light, but giving it to him *at a cut rate for current.* Yet, on examination the difference in average renewals per candle-power is not so great as it seems. It takes about five 16-candle-power incandescents to give the light of one 100-watt tungsten lamp, and their life is, on the average, considerably shorter. When the tungsten lamps get down to the plane of costs, which may fairly be expected, renewals for candle-power will be as low or lower than with carbon lamps. But until the high-efficiency lamp has stimulated consumption so as to hold up the central station income, free renewals will be a losing game.

"This existing condition must be met in some way.

Perhaps the most obvious scheme, aside from throwing renewals upon the consumer, is that of assuming renewals at a fixed charge, based on the average life. In this way the station using many lamps can average up the losses from short life against the gains from long life and come out square. Such is the policy often adopted by gas companies in putting out the so-called gas arcs, and it seems to work very well. This is one good reason for trying it in the case of the new lamps. Or, again, one could put the same amount in the form of an extra charge per kilowatt hour in which case the consumer would get only his ordinary meter bills. This extra-rate method, perhaps, does not look so well on paper as the former. At first sight it appears like a discrimination against efficiency, as if a gas company should charge one rate for gas used in flat-flame burners, and another for gas used in Welsbachs. It also complicates things if one works new and old incandescents on the same meter. In the last resort one must realize, too, that there is a considerable chance of still other high-efficiency incandescents appearing in the near future, having still other characteristics of life and economy, which will take still more time to evaluate. It, therefore, seems as though the safe course for the present would be to say frankly to the customer: 'Put on high-efficiency lamps if you want to—we are glad to furnish current for anything that comes along—but you will have to stand the expense until the costs of renewal become accurately determined, so that we can, in fairness to ourselves and to you, assume them.' Of course, the exigencies of sharp competition may justify a company in taking some long chances; but, save for these, a waiting policy would seem to be the wise one until the situation, as regards the new lamps, is far more stable than at present."

Likewise, in an editorial of March 28, 1908, the same journal wisely says: " . . . The lamp factories cannot now or in the immediate future turn out tungsten lamps fast enough to meet even a fraction of the demand; and when a company cannot get enough lamps to supply its customers, how shall it square itself with disappointed customers if it undertakes free renewals? It cannot give each customer his proportionate gain of the obtainable lamps, for a mixture of carbon and tungsten lamps is not only of objectionable appearance, but would be productive of unlimited kicking. It cannot properly distribute tungsten lamps by a lottery system, nor can it fairly discriminate between customers. . . ."

Policies of Prominent Central Station Companies with Respect to High-Efficiency Lamps.—The Edison Electrical Illuminating Company of Boston has always shown a progressive spirit in the matter of introducing modern devices on its circuits, and in handling the high-efficiency lamp situation it was one of the first large electric lighting companies to take the initiative. The renewal charges adopted by the company for various high-efficiency lamps are as follows:

In any case where an ordinary (carbon) lamp is supplied free, the 40-watt 20-candle-power tantalum is supplied at an excess charge of 30 cents; the 40-watt 32-candle-power tungsten is sold at an excess price of 45 cents, the 60-watt 48-candle-power tungsten at 55 cents, and the 100-watt 80-candle-power tungsten lamps are supplied at an excess charge of 65 cents each. The 150-watt tungsten is supplied at an excess charge of 90 cents, and the 250-watt tungsten at an extra cost of $1.15. The 100-, 125-, and 250-watt Gem lamps are now supplied free by the company, the carbon lamp in sizes above 16 candle-power

having been discontinued entirely. When the company renews an ordinary lamp free, taking back the old burned-out lamp, one of the new lamps is exchanged for the old one, plus the excess charge.

Up to the present the company's experience is that the new lamps are very effective in securing new customers. It is stated that nearly one-third of the new 100-watt tungsten lamps installed are for new customers, displacing 80-cent gas arcs, while about two-thirds installed for present customers temporarily decreased the income. About one gas arc is being replaced by $1\frac{1}{2}$ tungstens of the 100-watt size. In some few cases the gas arc is replaced by tungsten 100-watt lamps, saving the customer about one-third of his former bill, but the illuminating effect is not so good.

For residence lighting a small percentage of customers use tantalum lamps, but the number is decreasing because customers must pay any excess charge for lamps. The company is making an active campaign to introduce the new lamp to replace gas, but there is no decided effort being made to replace the company's own carbon lamps, except in the cases of dissatisfied customers.

In Chicago, The Commonwealth Edison Company recently adopted a proposition designed to meet the needs of consumers who have formerly used gas arc lamps. The plan is to install tungsten lamp clusters on a flat rate to be maintained and turned off and on by the company's patrolmen in the same manner as the flat-rate electric signs which the company has on its circuits. These clusters consist of four 60-watt, 50-candle-power tungsten lamps. Under a two-year contract the company will furnish, install, and maintain clusters and lamps for $1.15 per week; the lamps to be lighted from dusk until 10 P.M. six days

of the week and dusk until midnight one day of the week. Another contract provides for the lighting of tungsten clusters from dusk until midnight seven days per week for $1.50 per week.

The policy of The Brooklyn (N. Y.) Edison Illuminating Company is to furnish special high-efficiency lamps at cost, after an allowance covering the present cost of the carbon lamps furnished without charge to free renewal customers. In this way the customer secures all the benefit of the economy of the new lamps.

The 50-watt, 25-candle-power tantalum lamp is furnished to free-renewal customers of this company at an extra charge of 20 cents each. This lamp, as well as the 40-watt tantalum lamp, is supplied to free-renewal customers at 20 cents, subject to the return of the burned-out lamps. The following special prices have also been adopted for the several types of tungsten lamps to free-renewal customers, all subject to the return of burned-out lamps: 40-watt, 32-candle-power, 45 cents; 60-watt, 50 candle-power, 55 cents, and 100-watt, 80-candle-power, 70 cents.

The New York Edison Company has adopted the following schedule of prices on high-efficiency lamps:

Cp.	Type	Watts	Retail Plain	Price for High-Grade Frosted	Special Price to Free-Renewal Customers
16 ...	Carbon	50	$0.13	.....	Free Renewal
32 ...	Carbon	100	.20	.....	Free Renewal
20 ...	Gem	50	.16½	.....	Free Renewal
20 ...	Tantalum	40	.30	$0.31½	17½–19c.
25 ...	Tantalum	50	.30	.31½	17½–19c.
32 ...	Tungsten	40	.55	.58	40 –43c.
48 ...	Tungsten	60	.75	.79	52 –56c.
80 ...	Tungsten	100	1.00	1.06	62 –68c.

As a comparison of the relative status of the various lamps the New York Edison Company has prepared the following table:

COST TO CUSTOMER OF 10,000 CANDLE-HOURS OF ILLUMINATION

Cp. of Lamp	Type of Lamp	Watts	Cost of Lamp	Kw-hours of Current Consumed	Current Cost	Lamp Cost	Total Cost
16 . . .	Carbon	50	Free renewal	31.25	$3.12	$0.000	$3.12
20 . . .	Gem	50	Free renewal	25.00	2.50	0.000	2.50
25 . . .	Tantalum	50	Extra 30c.	20.00	2.00	0.15	2.15
32 . . .	Carbon	100	Free renewal	31.25	3.12	0.000	3.12
32 . . .	Tungsten	40	Extra 55c.	12.50	1.25	0.17	1.42

One of the most original and radically different methods of dealing with the tungsten lamp problem in residence lighting has been recently evolved by Mr. A. O. Dunham, president of the Hartford Electric Light Company. Tests were conducted for several months to ascertain the service possibilities of the smaller sizes of tungsten lamps designed for use on 30- and 60-watt circuits. These experiments have shown that such low-voltage, very-high-efficiency lamps will burn at least 2,000 hours, and on account of the larger filaments will withstand much rougher handling. The company is now engaged in introducing the lamps generally on its circuits. The exigencies of the situation demanded a new method of charging the customers for light used rather than billing installations on the customary system of a definite price per kilowatt hour. The plan as outlined by Mr. Dunham is to substitute a meter dial reading candle-power hours for the ordinary watt-hour dial of the ordinary induction meter, and charging the customer a rate of .025 cent per cp. hour of service

applied. The customer is charged for the initial installation, the charge being 20 cents each for either the 10-, 20-, or 30- cp. 30- or 60-watt lamps, and free renewals are given on all the lamps. The voltage suitable for the operation of the low-voltage lamps is reduced by means of an "economy coil" or compensator in each residence. Mr. Dunham explains his method of charging for light as follows:

"For the power used the customer pays for the actual kilowatts, but for the light delivered the customer pays for the actual kilowatts used plus the various other expenses which have been attached by custom and necessity. This has placed all the stations in a peculiar relation to the old-fashioned watt-meters in regard to the new lamps, and they find themselves reduced in income, if they use the new lamps, to one-half of their old revenue. This cannot be avoided except by changing the measuring instruments or by raising the price of the kilowatts used to double that charged for the old lamps, because the watt-meter measures a little less than half the actual cost of the candle-power.

"If you are selling light from 10-cp. or 16-cp. lamps, your customer is paying for the watts actually used plus all other expenses incurred—distribution, maintenance, lamps, and all other overhead expenses; that is, a sum which is calculated to double the watts used.

"The schedule of charges made by the same company (Commonwealth Edison) for tungsten clusters on a meter basis is as follows: The rental charge for a cluster containing four 60-watt tungsten lamps, including renewals, is $1 per month where the cluster is used 90 hours or less in the month, with an additional rental charge of 15 cents a month per cluster for each additional 15 hours of use (or fraction) over the 90 hours. In addition to the rental

charge there is a meter charge for electricity used by the cluster. The wording of the meter rate contract is interesting, as showing the equitable treatment which large central station companies are according their customers.

"In addition to said rental charge, the consumer agrees to pay the company for electricity consumed, 13 cents per kilowatt hour for the consumption in each month up to and including an amount that would be equal to 30 hours' use of the consumer's maximum demand in such month, and 7 cents per kilowatt hour for the consumption in such month in excess of that amount, provided that a reduction of one-half per cent per kilowatt hour will be allowed the consumer for all the electricity consumed in each month hereunder, and provided, further, that, whenever any monthly bill shall be paid at the proper office or agency of the company within ten days after its date, the consumer shall be entitled to a discount from such bill equal to one cent per kilowatt hour of the total consumption charged for therein. The electricity consumed shall be measured by a meter or meters to be owned and installed by the company. The maximum demand shall be ascertained by a maximum recording meter or meters, likewise owned and installed by the company, unless only one cluster is furnished hereunder, in which case the maximum demand for each month shall be taken to be 240 watts.

"We have only to remember that for the same kilowatts we should probably get an average of 5 cents for light instead of 10 cents as we do at present. Modern stations are organized for the distribution of light, more or less, some of them almost entirely for this purpose, and if they should substitute tungsten lamps for the 3.1 watt (carbon) lamp, would find their income cut in two. The customer would be using only one-half as much energy as with the 3.1 watt

lamps, and while the money paid for lights would include this energy, all the other costs would still remain, and the station would receive nothing for them unless the price per kilowatt hour could be doubled.

"For the business to survive and the plants to become actually without value, they must either double the price per kilowatt hour *in light* or get a meter measurement which will pay other expenses besides the watts used, and which enter into the question of candle-power supply. All questions as to the increased use of light on account of the lower cost, and the proper price to charge customers in consequence of the saving in the cost of production by using the new lamps, are entirely aside from this great basic fact that customers are now paying, not for the real kilowatts used, but for the kilowatt hours used plus the cost of distribution, maintenance, and all other overhead expenses."

The Dunham method of charging for light was illustrated by the following example: Suppose a private residence uses five graphitized filament lamps which are burned on the average of four hours per day. These are 20-cp. lamps burning 50 watts per hour each, or one kilowatt in four hours, for which the company charges 10 cents per kw. hour per day, or $3 per month. Expressed in terms of cp. hours this would amount to 400 cp. hours per day, or 12,000-cp. hours per month, for which the charge is 0.25 cent per cp. hour.

Should five 20-cp. tungsten lamps be substituted, giving 100 cp. for four hours per day at .025 cent, their cost at 10 cents per day is also $3 per month, or the same income received when the lower-efficiency lamps were used. Thus the company's income remains the same while the customer is given a better light.

The Tantalum Lamp, the second in importance of the

metallic filament lamps, is the invention of Dr. Werner von Bolton, chief chemist of the Siemens & Halske Co. (Germany). Although a light source of really wonderful efficiency as compared with the ordinary carbon incandescent lamp, it is so greatly excelled in efficiency by the tungsten lamp as to be almost overshadowed by the latter in America, but in Europe it is in extensive use.

Tantalum is a rare metal found by the scientist Ekeberg, in 1803, in a material obtained from Finland. It is black in color with a metallic lustre and is so hard that it is soluble only in hydrofluoric acid. The ores from which this metal is extracted are found only in a few places. Pure tantalum is harder than the hardest steel and can barely be scratched with a diamond; it will not rust; its fusing point is exceedingly high; it may be rolled into the thinnest sheets or drawn into the finest wire. At first the metal, which is of the same family as gold and silver, was very rare and costly. It existed, previous to Von Bolton's experiments, in a very impure form, so brittle that nothing could be done with it. New deposits of tantalum have recently been opened up in North Dakota and Australia, which have reduced its cost.

Chemical, Physical, and Electrical Properties of Tantalum.—The chemical properties of pure tantalum are very remarkable. When cold the material resists chemical agents strongly; it is not attacked by boiling hydrochloric acid, aqua regia, nitric acid, or sulphuric acid, and it is also indifferent to alkaline solutions; it is attacked solely by hydrofluoric acid. Heated in the air it assumes a yellow tint at about 400° C., like steel, and also like steel, the tint changes to dark blue when the tantalum is exposed for some time to 500° C., or for a shorter time to 600° C. Thin wires of it burn, when ignited, with low intensity

and without any noticeable flame. It greedily absorbs hydrogen as well as nitrogen, even at a low red heat, forming with them combinations of a metallic appearance, but rather brittle. It combines with carbon very easily, forming several carbides which, as far as they are at present known, are all of metallic appearance, but very hard and brittle. The product which Moissan thought was tantalum was clearly a carbide of this kind or an alloy of a carbide with pure tantalum. When in the form of powder still containing, as previously stated, oxide and hydrogen, the specific gravity is about 14; when purified by fusion and drawn into wire, it has a specific gravity of 16.8. It is somewhat darker than platinum and has a hardness about that of mild steel, but shows greater tensile strength than steel does. It is malleable, although the effect of hammering is relatively small, so that the operation must be rather long and severe to extend the metal into a sheet. It can be rolled as well as drawn into very fine wire. Its tensile strength as a wire is remarkably high and amounts to 133,000 pounds per square inch, while the corresponding figure for good steel is 100,000 to 112,000 according to Kohlrausch.

The electrical resistance of the material at indoor temperature is 0.165 ohms for a length of one metre and a section of one square millimetre (specific conductivity as compared with mercury, 6.06); the temperature coefficient is positive and has a value of 0.30 between 0 and 100° C.; at the temperature assumed by the incandescent filament in the lamp under a load of 1.5 watts per cp., the resistance rises to 0.830 ohm for a length of 1 metre and a section of 1 square millimetre.

Early Difficulties in the Manufacture of Tantalum Lamps.—The development of a commercial tantalum lamp pre-

sented some unusual difficulties due to the peculiar properties of the metal tantalum mentioned in the preceding paragraph.

In order to attain the construction of a practical and useful lamp for standard voltages and illuminating values, the problem was presented of drawing the tantalum wire in sufficient lengths to a diameter of 0.05 to 0.06 millimetre. In July, 1903, the first tantalum lamp was made with a filament of about 0.05 millimetre diameter. It had a bow-shaped filament about 5 centimetres long and its measurements were 9 volts, 0.58 amperes, and 3 candle-power at 1.7 watts per candle-power. On the basis of these figures a lamp having the same quality and diameter of wire and at the same economy on a 110-volt circuit must have a filament 65 centimetres long and would give 38-candle-power illuminating value.

The next problem was suitably and reliably to mount a filament rather more than 60 centimetres long within a glass globe which should not exceed to any great extent the dimensions of the usual incandescent lamps. Like all other metallic filaments which have been used for incandescent lamps, the tantalum wire presents the difficulty that it softens sensibly at the temperature corresponding with a load of 1.7 watts per candle. The employment of loop-shaped or spiral filaments was, therefore, impracticable. There was no difficulty in suspending the bows, but in such a design the lamps would have to be used exclusively in a vertical position, a limitation to be avoided under all circumstances.

It became clear to the inventors that the road to success lay in the direction of dividing the filament into a number of short, straight lengths supported at their ends in insulated holders. In this manner, in September, 1903, the

first really serviceable lamps for about 110 volts were produced. This lamp is illustrated in Fig. 26b, and it will be seen that it contains two glass supporters cast to a central wire holder; each support carries laterally 12 arms having small hooks at their ends and insulated from each other. Through these 24 hooks the thin tantalum wire is drawn up and down. This is believed to be the first metallic

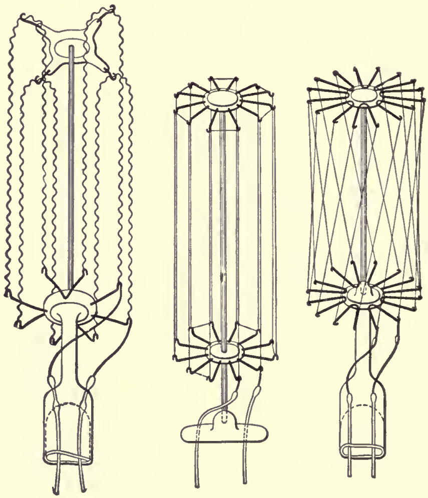


Fig. 26a. Fig. 26b. Fig. 26c.
Showing Evolution of Tantalum Lamp Filament.

incandescent lamp for nearly 110 volts, which, like the common carbon glow lamp, can burn in any position whatsoever. This lamp supplied about 25 cp. on a 94-volt circuit at 1.7 watts per cp. It lasted for 260 hours and lost during that time 9.5 per cent of its illuminating value.

Among other constructions tried, instead of one long filament a number of short pieces of wire were fixed on a supporting frame; these pieces, connected in series, made

up the total length required. Fig. 26c represents a lamp thus constructed, the wire being strung obliquely in 16 straight pieces between two insulated supporting stars. Such lamps offer the advantage that short pieces of filament can be used in the manufacture. But they are only reliable if the wires used in the same lamp are absolutely uniform in diameter and quality. In the end the shape was arrived at represented in Fig. 27 for 110 volts, 22 cp. and 1.7 watt per cp.

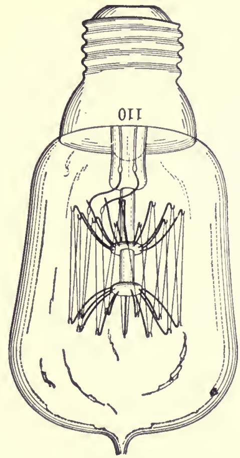


Fig. 27.—Typical Present Form of Tantalum Lamp.

In this form, differing from most of the previous constructions, the central support consists of a short glass rod carrying two supporters into which the arms, bent upward and downward in the shape of an umbrella, are cast. The upper star has 11, the lower 12 arms, each upper arm being in a vertical plane midway between the vertical planes in which two adjacent lower arms lie. Between these 11–12 arms, which are bent into hooks at their ends, the entire length of the filament is drawn zigzag. Its extremities, held by two of the lower arms, are connected with the foot of the lamp by means of platinum strips.

The standard type for 110 volts, 22 cp. and 1.7 watt per cp. has a filament 65 cm. long and is 0.05 mm. in diameter. The weight of this filament is 0.022 grams, so that about 45,000 lamps contain together 1 kilo of tantalum.

The shape of the glass globe is adapted to the frame

described above. Care is taken to make it of a size not exceeding the usual maximum dimensions of common incandescent lamps of the same candle-power.

This shape offers a number of noticeable advantages. In the first instance it is very stable and will stand strong shocks without damage to the lamp. A considerable number of such lamps, sent across the sea to try their resistance to the hardships of transport, came back unhurt, although they were packed just like common glow lamps and no special care in any respect had been taken in their handling. The lamp burns, of course, in any position and can, therefore, be supported in any kind of fitting. Fig. 27 illustrates a typical tantalum lamp.

Current Consumption and Useful Life of the Tantalum Lamp.—Carefully conducted tests for lengthy periods of time, at loads varying within the range of 1.2 to 3.4 watts per candle, have shown that the tantalum lamp consumes nearly 50 per cent less current at the same voltage, with the same intensity of light and the same useful life, than the carbon filament lamp; or it gives double the light of the carbon filament lamp while its maximum life, at the same economy, is several times that of the carbon type. Again, at an initial load of 1.7 watt per candle-power the tantalum lamp has an average life quite sufficient for all practical requirements, hence the rate of consumption is standard for the 110-volt lamp. Tests on loads of 1.2 watts per candle show that the lamp has a life of several hundred hours, but when burned on such wattages the lamps are very sensitive to variations of pressure and often showed an early decrease of illuminating value. The useful life of the tantalum lamp, *i.e.*, the life within which it loses 20 per cent of its initial illuminating value, averages between 400 and 600 hours at 1.7 watt per candle-

power. Some specimens have proved to have a useful life much above 1,200 hours. The absolute life is in general much longer than the useful life and amounts to an average of 800 to 1,000 hours under normal working conditions. Further the tantalum lamp blackens but little, unless it has been strongly overheated during work in consequence of partial short-circuiting of the filament.

As to the behavior of the tantalum lamp during the whole course of its life, the first fact worthy of note is that,

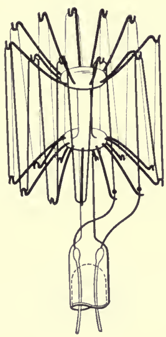


FIG. 28.

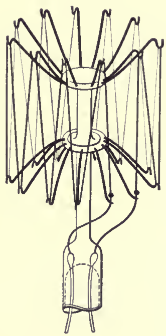


FIG. 29.

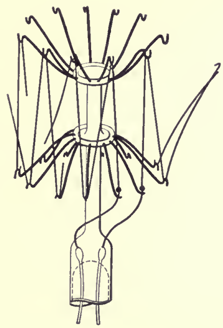


FIG. 30.

like some carbon lamps, the illuminating value increases at the beginning, generally after a few hours, by 15 to 20 per cent. In the same way the consumption of current rises about 3 to 6 per cent, while the consumption of energy decreases. After that the illuminating value gradually decreases with a corresponding increase in the consumption of energy.

Fig. 28 represents the filament frame of a new lamp. It will be noticed that the tantalum wire is led up and down and hangs loose on the supporting frame in easy, wide arches, without any sharp bends. But after being

used for some time the aspect of the lamp is quite different. As shown in Fig. 29 the wire has contracted, the wide arches have disappeared, and sharp-pointed angles have taken their place.

While with all other incandescent lamps the burning through of the filament is tantamount to the economical death of the lamp, it may happen with tantalum lamps that they burn through several times without loss; on the contrary, each burning through is followed by an increase, often considerable, of the illuminating value. This peculiar result is due to the fact that in many cases a broken wire comes in contact with its neighbor, so that the circuit is again established. A part of the filament is thus cut out of the circuit and the lamp consequently burns more intensely and sometimes even too intensely, in which case, of course, it has only a short span of life. Yet in more than one lamp under observation the filament broke after a short period of service and then broke repeatedly, but notwithstanding this the lamp had a life of more than 1,000 hours. A lamp with a broken filament has been made serviceable again by tapping it to bring the broken piece into contact with its neighbor. Fig. 30 represents the frame of a lamp where the filament was burned through in three places and yet continued to do service. For the sake of clearness the back spans of the filament have been omitted in the drawing, while the front spans which were carrying the current are drawn in specially heavy lines.

After serving for some time, say 200 to 300 hours, the tantalum filament loses a great deal of its mechanical resistance. While tantalum wire, when new, has a greater tensile strength than steel, it becomes brittle and will break easily in the course of its life as a filament. It is,

therefore, advisable, when lamps have served for some time, not to remove them from their old fittings and put them into new ones, as that might easily cause the filament to break. New lamps are not very sensitive to strong shocks, even while burning, but when this alteration in the filament has happened, it is well to preserve them from shocks.

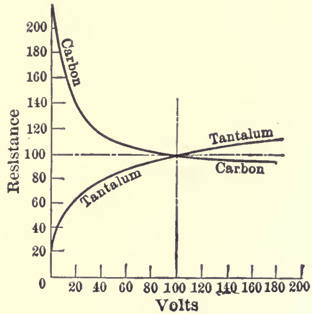


FIG. 31.—Curves of Carbon and Tantalum Resistance.

Fig. 31 shows the comparison curves of carbon and tantalum resistances.

Fig. 32 shows the construction of an English type of 200-volt 32-cp. tantalum lamp. To obtain the necessary resistance two filaments connected in series are used.

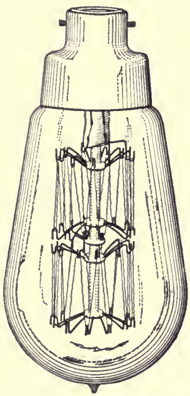


FIG. 32.—A 200-volt Tantalum Lamp

Behavior of the Tantalum Lamp in Service.—After burning for a considerable while the filament of a tantalum lamp presents a radical change in appearance when viewed with the naked eye. Although the new filament has a perfectly smooth and cylindrical surface, it acquires a singularly glistening aspect as the filament gets older; hence a lamp that has been in use for some time can be readily distinguished from a new lamp.

An investigation was conducted by Mr. M. D. Abbott, of the University of Nebraska, to determine the behavior of tantalum lamp filaments under

the action of alternating, direct, and intermittent direct current.

The lamps used in this test were of American make and were rated at 20-cp. and 110 volts. The measured diameter of the filament was 0.0017 in. with a tensile strength, as obtained from tests made on two samples, of 225,000 pounds per square inch, being thus much stronger than steel. The lamps were suspended from coil springs placed

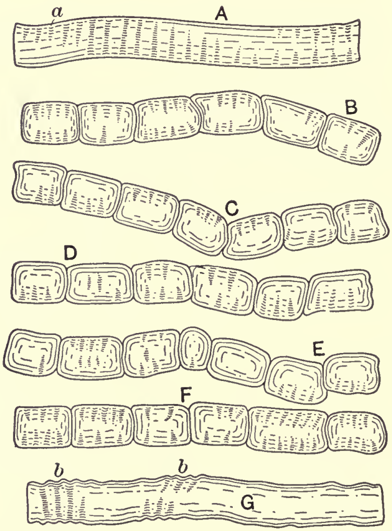


Fig. 33.—Faulting of Tantalum Filament on Direct Current.

between two supports and connected two in series to 220-volt mains. The illustrations of the faulting, Figs. 33 and 34. were drawn from observation of the filament taken under the microscope. The data on these figures are as follows:

Direct current—*A*, 148 hours; *G*, 423 hours (of burning).

Intermittent direct current—*B*, 17 hours; *C*, 25 hours, *D*, 35 hours; *E*, 137 hours; *F*, 84 hours.

Alternating current—*H*, 42 hours; *I*, 51 hours; *J*, 58 hours, *K*, 79 hours; *L*, 126 hours; *M*, 393 hours; *N*, 619 hours.

The tensile strength of the filament shown at *A*, tested under direct current, was found to be greatly reduced at the end of the run and varied from 30,000 pounds to 60,000 pounds per square inch. The color had changed from a

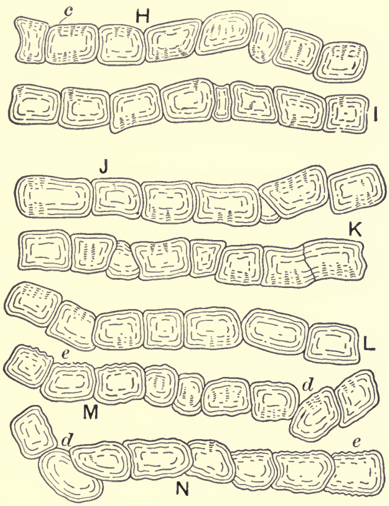


Fig. 34.—Faulting of Tantalum Filament on Alternating Current.

silver gray to a dull black, and slight depressions or creases are noticeable, as represented at *a*, which in some portions extended nearly across the surface. *G* shows the filament to be very ragged. Small waves or crests and hollows as shown at *b b*, appear on parts of the surface. The filament is brittle, but strong enough to withstand a moderate jar or shock. The color is a glossy black.

The effect of alternating current is shown at *H*, *I*, and

J. Slight depressions or pittings are distributed throughout its length, as shown at *c*. The color of *H* is a glossy black. *K* and *L* show phases of change in the filament. The color changed to a very glossy black. At *M* and *N* is shown a very marked deterioration of the filament at the joints, and as shown at the points *d d*, the segments in some places have slipped so that only a small area is in contact. Small crests and hollows, as shown at *e e*, appear on portions of the filament, the color being a glossy black. The filament in all cases when supplied with alternating current, even for brief intervals, became very brittle and its strength was so affected as to render it subject to injury from slight jars or shocks.

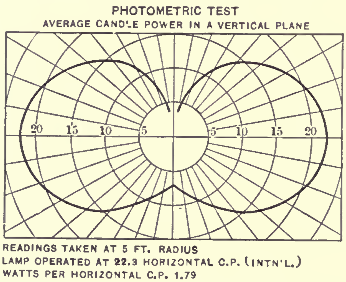


FIG. 35.—Polar Curves of Tantalum Lamp without Reflector.

In the test used with intermittent direct current, the current used, with the exception of *F*, was delivered from a commutating device which produced equal periods of on-and-off-circuit, and the frequency was such that only a slight flicker was noticeable at the lamps. The voltage was regulated so as to produce the same luminosity as when on alternating or direct current. Except for the absence of the crests or hollows observed in the alternating-current experiments, intermittent direct current produced results similar to the former. *F* shows the results of a skeedoodle service produced by a "skeedoodle device" (a special socket used for flashing lights on and off in electric signs). The faulting did not appear uniform throughout the length of the filament, as shown by the long segment

on the right of F. Some portions showed an even greater length apparently not broken up, but on close inspection fine lines were noticeable running across the filament in a transverse direction, which showed the beginning of a joint. The color was dull black.

Principal Field of Service of Tantalum Lamp.—The disadvantages of tantalum lamps—chiefly the high cost of tantalum—have been mentioned, from which it can be seen that this type of metallic filament lamp has not met with the same degree of popularity as the tungsten lamp. The majority of the tungsten lamps used in this country are of the 50-watt 25-cp. and of the 40-watt 20-cp. ratings.

The tantalum lamp has met with the best success under conditions where the central station does not give free renewals of carbon lamps, as customers of such stations, being in the habit of buying their lamps, will more readily use tantalum lamps—which is true of all the metallic filament lamps.

The majority of tungsten lamp installations have been made in isolated plants. Its most satisfactory service has been accomplished in such plants in reducing the strain on overloaded machinery, and in affording increased illumination without increase of generating equipment. Unlike some of the other metallic filament lamps the tantalum lamp can withstand vibration and rough service and hence is very valuable for train and automobile lighting, and in any service where shocks and jars would prohibit the use of the tungsten lamp.

The Osmium Lamp.—The invention of this type of metallic filament lamp is due to Herr Welsbach, of Welsbach gas-mantle fame. The osmium metal possesses many of the characteristics of tungsten, being so highly brittle that it can be made into filaments only by mixing the finely

divided particles with an organic binding material. This binding material is subject to a carbonizing process in the manner described under the making of tungsten lamps, the filaments then being treated white hot in a reducing atmosphere to get rid of the carbon.

The introduction of the osmium lamp has been slow, due to the fact that osmium is chiefly found in nature associated with platinum, which is itself a comparatively rare metal, and the supply has been obtained by refining platinum ores. So difficult is osmium to obtain that manufacturers of these lamps buy back burnt-out lamps for some of their supply of osmium. Another important limitation to the use of osmium lamps is their unsuitability to high voltages. The osmium filament is also, if anything, more sensitive to damage or rupture from vibration or shocks than the tungsten lamp.

The extreme brittleness of osmium prevents its manufacture into filaments of great length; and when heated the filament is so soft that it must be carefully supported in order to maintain it in its proper position. The manufacturers of osmium lamps guarantee them for 500 hours; when kept free of jars, etc., the filaments will sometimes burn several thousand hours. The average specific consumption of 16-cp. osmium lamps throughout their life is 2 watts per candle-power.

The Helion Lamp is the invention of Messrs. Parker and Clark, professors in Columbia University, New York, and may be termed a cross or compromise between the carbon lamp and the metallic filament lamp. The filament is a very small core of carbon mounted in a bulb like the ordinary incandescent lamp and subjected to the flashing process of the carbon lamp. Use is made of a gaseous compound containing silicon for flashing instead of hy-

drocarbon gas. In the early stages of the deposition the metal appears to be taken up by the pores of the carbon, but as the flashing proceeds the filament takes on a surface deposit. This surface coating causes the light emission of the filament to increase greatly and the color of the light changes from the characteristic color of the carbon lamp to an almost pure white. As soon as the deposit is sufficient to give the filament a certain resistance the deposit is discontinued, the bulb is exhausted and sealed as in the case of carbon lamps. The Helion lamp, while hardly in the commercial stage (the first lamp being shown in 1907), possesses characteristics which will perhaps make it a competitor of the newer types of incandescent lamps.

An interesting property of the filament is its high specific resistance, which is almost fifty times greater than that of the carbon filament and several hundred times that of tungsten. The filament is also very hard, it being possible to scratch glass with small particles of it under the thumbnail. A striking property also of the filament is its remarkable resistance to oxidation and it is possible even to burn the lamp in the open air without any enclosing glassware, the efficiency under such treatment ranging from 2.5 to 4 watts per candle. It may be maintained at a bright incandescence for many hours without deterioration, at a temperature approximating 1,800° C. If burned in air, however, the filament receives a deposit of atmospheric dust which, coming in contact with it, is fused and adheres, so that in time the filament begins to show excrescences and burns in two. Hence, for physical as well as mechanical reasons, the filament is enclosed in an exhausted bulb, its useful life in this case being claimed as several thousand hours of burning. Fig. 36 shows the appearance of the

Helion filament burning in air; Fig. 37 is an illustration of the lamp burning in a vacuum bulb.

The filament is of great strength, can be burned in any position, and neither high temperature nor excess voltage damages it. Indeed, the incandescent Helion filament may be plunged in water without any other apparent effect than the cooling effect produced by the water. It is also possible to cut through pieces of glass by allowing the

Fig. 36. — Helion Lamp Burning in Air.

Fig. 37. — Helion Lamp in Vacuo.

filament to melt its way through the glass, which it will do without seeming injury to the filament.

In experiments conducted by the Electrical Testing Laboratories of New York, the specific energy consumption of the Helion lamp was close to one watt per candle-power, while the decrease in candle-power during its life was small.

Due to the presence of blue rays in its spectrum the color value of the Helion lamp approximates daylight. Its high efficiency and durability will undoubtedly make it a valuable electrical illuminant of the future.

The Titanium Lamp.—Titanium, though generally

spoken of as one of the rare elements, is really one of the more common ones. According to Dr. F. W. Clarke, chemist of the United States Geological Survey, it forms 0.43 per cent of the surface rocks of the globe, and is much more plentiful than lead, zinc, copper, and other metals classed as "common." A great many schists and gneisses carry titanium, and it is found in appreciable quantities in clays—not only surface clays, but also those that have been dredged from the sea-bottom. In a report on titanium by Mr. F. L. Hess of the United States Geological Survey the author says: "Several firms are now experimenting with titanium filaments in incandescent electric lamps, but the reduction of titanium to a metal is so difficult that the lamps have not been extensively placed on the market. Titaniferous magnetite and titanium carbide, the titanium of which is derived from rutile, are used as electrodes in arc lamps. When one electrode is made of these substances a block of carbon is used for the other. The best-known rutile deposit in this country, the one which produced the greater part of the titanium output in 1906, is at Roseland, Nelson County, Virginia. . . ."

The titanium lamp of Walker, brought out in 1901, was the first type of this lamp. The filament was shorter than that of the carbon lamp and was made of the carbide of titanium produced in the electric furnace. The first filaments were designed to withstand pressures of 500 volts, which demanded the use of larger bulbs, and trouble ensued on account of the leakage across the base of the lamp, which, when the vacuum was poor, resulted in rupture of the filament.

Authentic tests conducted on the early types of titanium lamps showed a comparatively good efficiency, the initial

specific consumption being 2.53 watts per candle-power, 2.8 watts after burning 500 hours, and 3.35 watts per candle after burning 1,000 hours. Until chemists develop more efficient methods of reducing titanium ores to the metal the future of titanium will not appear bright; in fact, even if this difficulty did not exist, the lower efficiency of the titanium filament would debar its extensive use.

The Nernst Lamp is the invention of Dr. Walther Nernst of the University of Göttingen (Germany), and while essentially a "glower" lamp, it has some of the characteristics of the enclosed-arc lamp, in that its operation is partly thermal and partly electrolytic. The conducting medium, or "glower," of the Nernst lamp was composed in the original lamps of the rare earths of zirconium, thorium, magnesium, yttrium. As manufactured at present the glower consists of a combination of the rare earths of volcanic production, including zirconium, wöhlerite, gadolinite, luxenite, yttrotitanite, yttrocerite, samarskite, cyrtolite, alvite, eudialyte, polykras, and kataplite.

Of these rare earths, the properties of the last three named were but recently discovered, and their marked influence on the efficiency and life of the new glowers determined.

This glower material when refined has five times the value of gold. Of no less importance to the success of the lamp is the fact that platinum, though more expensive than gold, is used in connection with the glower, heater, and other parts.

The essential parts of the Westinghouse-Nernst lamp as manufactured by the Nernst Lamp Company, Pittsburg, comprise a *glower*, *heater*, *holder*, *ballast*, and cutout, and a suitable housing with enclosing globe. Nernst lamps are constructed with either a single glower or with a plurality of glowers, ranging as high as five glowers per lamp.

The glower (Fig. 38), composed of a complexity of rare earths, is of tubular shape and of small diameter; and connections are made to either end by means of small platinum wires. Glowers designed for use in direct-current lamps are made as porous as possible to obviate electrolytic action, while the glowers for alternating-current lamps are vitrified and are constructed with greater strength.

The peculiar nature of the material of which the glower is composed renders it a non-conductor of electric current when cold, hence it must be heated to a certain temperature before it will admit the passage of current and emit light. This is accomplished by a heater, which, on account of its shape, is termed the *wafer heater*, and is operated electrically. The heater is placed above and close to the glower and both are enclosed by a glass globe. As the Nernst lamp does not require a vacuum, the enclosing globe is not air-tight. The heater consists of a small platinum-wound and refractory cement-coated rod, bent so that the several sections lie parallel to the glowers and are securely mounted on a flat porcelain (Fig. 39). The wafer slides on the heater prongs when inserted in the holder; the heater terminals being in the form of a sleeve contact.

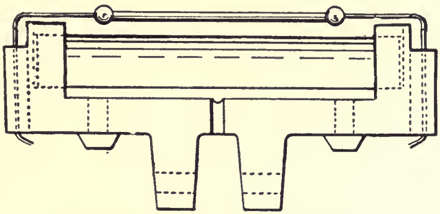


Fig. 38.—Glower of Nernst Lamp.

The holder for the multiple-unit Nernst lamps consists of a one-piece holder base, to which are attached the terminal prongs. Two prongs are brought through the holder base and are secured in such a manner that they lie in a plane parallel to the glowers and at right angles to them.

The Westinghouse-Nernst lamps have been very recently equipped with a new type of spring holder designed to supplant the type referred to above. This holder (Fig. 40) consists of a one-piece porcelain base identically like that shown above, but is equipped with a different device for holding the glowers. On one side is attached a metal stamping consisting of a series of springs, one for each glower, covered by a metal guard. A corresponding number of rigid upright supports fit into slots in the opposite side of the porcelain. The glowers are received by small platinum jaws welded to the tips of the springs and to the tips of the upright supports.

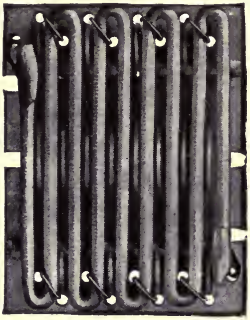


Fig. 39.—Heater of Nernst Lamp.

The glowers are fitted with fused beads at the ends of the platinum jaws, which prevent them from slipping through the jaws of the holder. The operation of replacing a glower is so simple that it can be performed by the average person, and consists of inserting the beads of the glower in the jaw on the spring side of the holder and then drawing the spring forward sufficiently to permit the other beads to drop into the corresponding slot on the opposite side of the holder. The spring tension draws the glower into position automatically without further attention. The new spring holder

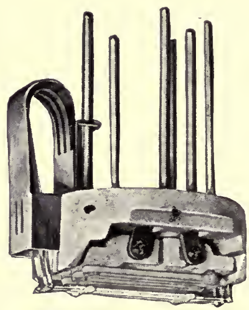


Fig. 40.—Present Type of Holder of Nernst Lamp.

reduces the time of replacing a glower and renders it impossible to replace the glower in any other than the proper way, and also reduces the cost of maintenance by 30 per cent over the old form of holder using heater tubes.

In the upper part of the lamp is placed a ballast, which is a small regulating resistance connected in series with the glower, and also an automatic cutout, the function of which is to disconnect the heater as soon as the glower comes up to incandescence. Unless the voltage is abnormally high, the ballast is liable to no injury, and in no case by turning current on and off. The ballast is, therefore, fitted with *ballast coolers*, which consist of strips of flexible phosphor bronze, fixed to the upper part of the lamp housing in such a way that a firm contact is made on the surface of the ballast and a metallic contact is secured with the housing, thereby providing a large radiating surface.

The function of the ballast coolers is to provide simply a very rapid dissipation of heat, so that the ballast itself will not be sluggish in action—*i.e.*, so that it will respond immediately to any change in voltage and thereby maintain practically constant current for varying voltage.

The heater is fixed horizontally above the glower, which is itself horizontally placed. (A sectional view of a single-glower Nernst lamp with parts indicated is shown in Fig. 41.) On switching a Nernst lamp in circuit the heater is in circuit, but as the glower warms up, the current passing through it operates an electro-magnet which is connected in series with the glower and which cuts the heater out of circuit. A specially refined soft grade of porcelain is used in the heater to prevent unequal expansion of the porcelain and platinum and the working of the current through the porcelain. The lamp-makers guarantee a life of 2,500 hours for the tube.

Owing to the high "negative temperature coefficient of resistivity" of the glower, means must be taken to counterbalance this by a large positive temperature coefficient of resistivity, otherwise an excessive current would pass through the glower and destroy it.

This compensating resistance consists of a pure iron wire

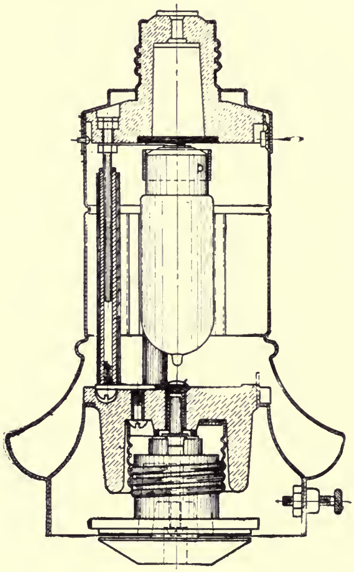


FIG. 41.—Sectional View of Single-glower Nernst Lamp.

placed in a glass tube which is charged with an inert gas, usually hydrogen, to obviate rust and deterioration, but principally to dissipate the heat liberated by passage of current. The mount contains wire of proper length and diameter to give rated current at rated voltage with desired characteristic—at atmospheric pressure of the hydrogen. The ballasts are, therefore, merely filled with hydrogen under uniform pressure of one atmosphere.

Westinghouse-Nernst lamps are made in seven units for use on both alternating and direct current of 220 volts, and three units for both alternating and direct current, 110 volts; for indoor and outdoor service. These are commonly termed 66-, 88-, 110-, and 132-watt single-glower, two-, three-, four-, and five-glower lamps.

The normal range of operation of standard glowers varies from 200 to 260 volts for 220-volt ratings, and 100 to 130 volts on 110-volt rating. The adjustment of Nernst lamps for use on circuits of various voltages is effected in the holder, and merely requires the employment of different glowers.

Fig. 42.—Single-glower Nernst Lamp.

The efficiency of Nernst lamps increases with the number of glowers (up to the number of glowers practicable to use), due to the higher temperature gained from the closeness of the lighting units.

The Westinghouse-Nernst single-glower lamps are of the Edison base type and present a similar appearance to the 110-watt unit, although the construction is different. (Figs. 41 and 42.) The cutout is located within the Edison base, from which the prongs lead to a porcelain base on whose lower side is a screw receptacle, while on the upper side is the ballast.

The holder consists of a glower and a wafer heater permanently connected on a small porcelain provided with a standard screw base, with an additional contact pin in the centre. (Figs. 40 and 41.) By an assortment of diameters and lengths of contact pin, it is impossible to insert any other than the proper holder in the lamp body, thereby

insuring the consumer against troubles incident to the use of lamps of various size and voltage.

Color and Distribution of Light from Nernst Lamp.—The color of the illumination from the Nernst lamp is a pearly white, yet it possesses sufficient softness and warmth to render it very serviceable for a variety of illuminating

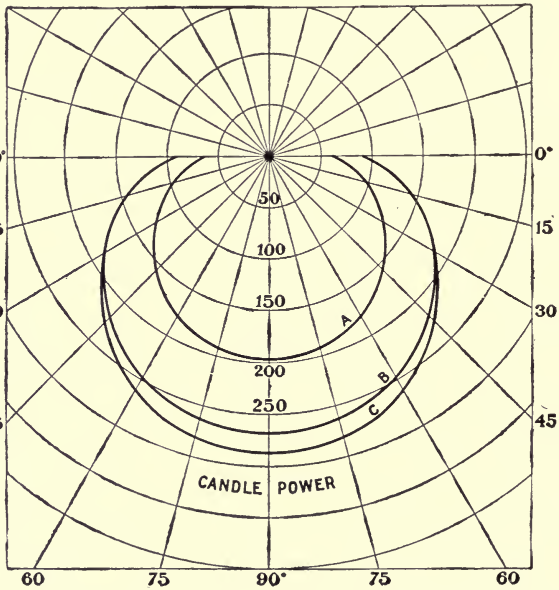


Fig. 43.—Curves Showing Vertical Light Distribution of Nernst Lamp.

work. One of the most notable installations of Nernst lamps in America is that of the large merchandizing establishment of Marshall Field & Co., Chicago, in which 6,000 Nernst lamps of various sizes are employed, mainly of the two- and three-glower type. This installation replaced nearly 58,000 incandescent electric lamps.

The Nernst lamp has been developed with a view of

making its maximum intensity of illumination in the vertical direction, as can be seen from an inspection of the photometric curves (Figs. 43 and 44). The following tables show, respectively, the candle-power of Nernst lamps delivered at various angles (Table I, page 113), while Table II, page 113, shows the hemispherical candle-

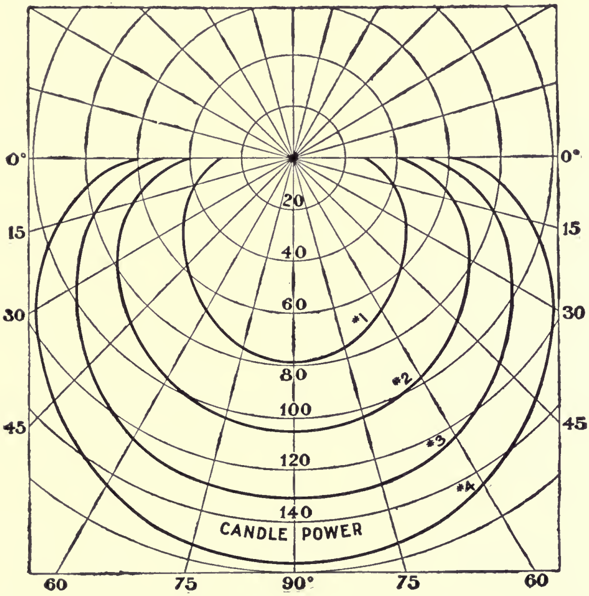


FIG. 44.—Photometric Curves of Single- and Multi-Glower Nernst Lamp.

power and efficiency obtained in the various types (these tables being taken from the manufacturer's publications).

The resistance of the glower of the Nernst lamp undergoes a steady increase in service. The accepted explanation of this is the change in its structure from an amorphous condition resembling chalk when new, to a rough crystal-

line state which it takes on after burning several hundred hours.

The life of Nernst lamps compares favorably with that of the metallic filament incandescent lamps already discussed, as is evident from the table below, which is a summary of the life of the various elements. These figures apply to any installation of over 100 units for the average life performance when operated on a circuit whose regulation is 5 per cent above or below the normal point of operation. The author's observations have shown that the guaranteed figures are very conservative, as under good conditions the useful life of such lamps is 30 to 40 per cent higher.

Part or Element Parr	HOURS LIFE							
	Direct Current		Alternating Current					
			25 Cycle		60 Cycle		133 Cycle	
	110 V.	220 V.	110 V.	220 V.	110 V.	220 V.	110 V.	220 V.
Glower		600		400		800		800
Heater.......		3000	3000	3000	3000	3000	3000	3000
Ballast	15000	15000	15000	15000	15000	15000	15000	15000
Screw Burner .	600	600	400	400	800	800	800	800

Since this volume was commenced the American-made Nernst lamps have been equipped with a new type of luminous heater which renders them instantaneously lighting. Instantly the current is turned on the heater emits light and heat, consuming about 7 watts per candle, including loss by absorption in the glassware, and also lights the glower in from 10 to 12 seconds of time.

TABLE No. I

Lamp at 220 Volts	Glass-ware	Maximum Candle-Power	Mean Hemisphere Candle-Power	Mean Hemi-sphere Efficiency	Actual Wattage Under Test
1 Gl., 66 watt	4″	74	50	1.38	69 (110v.)
1 " 88 watt	4″	105	77	1.2	92
1 " 110 watt	5″	131	96.4	1.2	115
1 " 132 watt	6″	156	114	1.2	136.8
2 Glower	8″	345	231	1.2	276
3 "	8″	528	359	1.15	414
4 "	8″	745	504	1.09	552

TABLE No. II

Type Lamp	Candle-power at Various Angles of the Horizontal							
	85	75	65	55	45	35	25	15
1 Gl., 66 watt	74	73	70.5	65	59	52	45.5	39
1 " 88 watt	105	103	100	95	89	82	73	64
1 " 110 watt	131	130	128	122	112	103	93	79
1 " 132 watt	156	155	149	141	133	122	107.5	94
2 Glower	345	342	333	313	289	264	226	170
3 "	528	525	512	496	443	405	353	267
4 "	745	738	722	685	628	576	495	373

CHAPTER IV

ARC LAMPS

The Flaming or Luminous Arc Lamp.—This type of arc lamp is the invention principally of H. Bremer, who first placed the commercial "yellow arc lamp" on the market, in 1899. Similar to nearly all important inventions, the flaming arc also had forerunners, and its history is a gradual evolution from the experiments of Casselman in 1844, who suggested the employment of the salts of copper, strontium, and zinc in the carbon electrodes of arc lamps to modify their color. His experiments were continued by French chemists, notably by Carré and Archereau in France.

The electrodes of the flaming arc lamps consist of carbons to which mineral substances are added, chiefly fluorides of alkaline minerals, which cause the arc or vapor stream to be extended to considerable length and at the same time to become luminous, increasing thereby the luminosity of the light. In the ordinary enclosed carbon arc, 95 per cent of the light comes from the incandescent crater of the upper carbon, whereas in the flaming arc, 25 to 35 per cent of the light emitted is due to the intensely luminous vapor stream.

The principle of Bremer's first flaming arc is shown in Fig. 45, which also shows the characteristic design of the flaming arc lamp, the salient feature of which is the arrangement of the electrodes in an inclined position. In the class of superposed electrode lamps using flaming car-

bons, so-called luminous arcs, are included magnetite lamps, Blondel lamps, and titanium-carbide lamps, together with Carbone lamps, using inclined electrodes, but not impregnated with metallic salts. These will be discussed in later pages.

In his experiments with the flaming arc, Bremer discovered that the use of the electrodes in a vertical position in the lamp resulted in the formation of a kind of slag deposit on the tips caused by the mineral admixtures, which, being non-conductive, interfere with the uniform operation of the arc or unsteady it to an objectionable extent. Various means, such as, for instance, the use of water glass or boracic acid in the carbons, were tried to overcome the objectionable effects of the slag, but the only practicable method of overcoming the trouble consists in arranging the carbons in an inclined position, with their active ends converging so that no slag will form in the path of the vapor. An additional advantage of the inclined position of the carbons is that nothing can obstruct the light of the arc, as is the case in the vertical electrode arc.

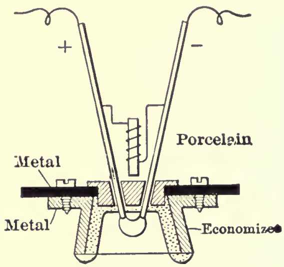


Fig. 45.—Arrangement of Original Bremer Flaming Arc Lamp.

Two further elements of much importance in flaming arcs are the "economizer" and the "blow magnet." Referring to Fig. 45, the economizer of the original Bremer lamp will be seen to consist of a truncated metallic cone surrounding and supporting a porcelain dish through which the carbons are inserted. Its purpose is to increase the efficiency of the arc by concentrating the heat, and to

lengthen the life of the carbons by limiting the air supply. The economizer also acts as a reflector, owing to the white deposit of the arc flame settling on it, thus throwing most of the light in a downward plane.

The function of the blow magnet is to prevent the arc from climbing up and damaging the economizer, particularly when the carbons are nearly burned out. When this occurs the arc is blown away by the magnet or if necessary extinguished. The blow magnet can also be used to spread the shape of the arc as may be desired, preferably, however, into the form of a reversed umbrella. This feature of the blow magnet makes it possible to increase the diameter of the carbons and thus lengthen the period between trimmings.

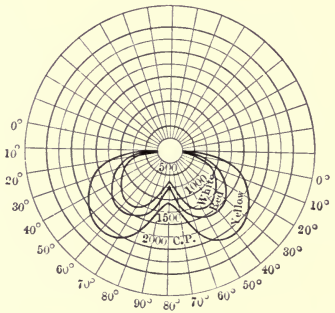


Fig. 46.—Influence of Flaming Arc Color on Light Emitted.

In most uses of the flaming arc, however, a blow magnet is not required, since the electric arc is itself a magnetic field generator and tends to force the arc away from the tips. Under some circumstances, as for instance, with a 12-ampere flaming arc, it might become necessary to use the blow magnet to produce a reverse action, that is, draw back the arc toward the carbon tips instead of forcing it away from them.

There are three kinds of flaming arc carbons in commercial use, *yellow, red,* and *pearl white.* The yellow, which is the more extensively used, is produced by the admixture of calcium (lime) salts in the carbon in the form of a core. The red flaming arc, which in practice is more nearly

a light pink, is produced by the use of strontium s
The white color is produced by the use of barium s
The most efficient of the three is the yellow carbon which is, as stated, the most popular. The illuminating power of the white-flame carbon exceeds but slightly that of the open arc with pure carbons, the red carbon having an intrinsic brilliancy slightly above that of the white. Fig. 46, which is from a paper by Mr. S. H. Blake on "Flaming Arcs," shows the decided influence of the color of the flame upon the light emitted.

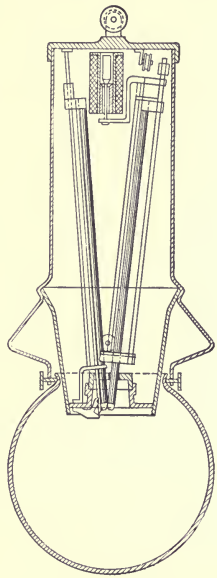


Fig. 47.—Gravity Feed Beck Lamp.

Limiting Percentage of Metallic Salts.—There is a critical limit to the admixture of metallic salts in the electrodes of flaming arcs, which, if exceeded, does not increase the light intensity rapidly. While Bremer's first flaming arc carbons were highly impregnated with the salts of such metals as barium, calcium, strontium, etc., it was later discovered by Prof. W. Wedding that the salt mixture should not exceed 15 per cent, to obtain the best results. This is due to the fact that the slag deposit previously referred to increases with the percentage of metallic salts, causing the arc to become unsteady. In the best practice of to-day, the metallic salts are only added to the core, the solid portion of the electrode consisting of pure carbon. In this way the slag deposits are of negligible importance, although the light emitted is less than it is in carbons more highly impregnated with salts.

Limitations of Dimensions of Flaming Arc Carbons.—To insure steadiness in the flaming arc due to the long flame or vapor stream, the diameter of the carbons must be kept within certain limits, which shortens their life considerably. The most convenient means of increasing the life of the carbons is to increase their length; this causes an increase of resistance which makes the resistance of the flaming arc rather higher than that of the ordinary carbon arc. Some makers of flaming arcs have sought to overcome this by coating the electrodes with a metallic vein of copper deposited by electrolytic means on the surface of the carbon.

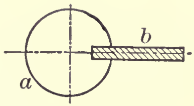


Fig. 48.—Detail of Beck Lamp.

Mechanical Construction of Flaming Arc Lamps.—Although the electrical features of all types of flaming arcs are practically alike, their mechanical construction differs widely; and in the present state of the art five distinct types exist, all of which possess distinguishing advantages and objections. According to the method by which the electrodes are controlled, electro-mechanically flaming arc lamps employ either (1) a gravity feed mechanism; (2) clutch mechanism; (3) clock mechanism; (4) hot wire mechanism, or (5) motor mechanism.

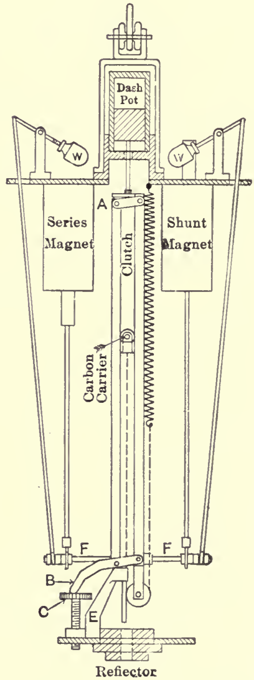


Fig. 49.—Type of Clutch Mechanism of Flame Arc Lamp.

The most interesting type of gravity feed flaming arc lamp is the Beck lamp, which is shown in Fig. 47, and is the simplest of this type yet devised. The regulation and operation are entirely by gravity, the carbons sliding down into proper position by their own weight and are prevented from coming too far by means of the rib *b* shown in detail (Fig. 48), which projects from one of the carbons and is supported by a small shoulder attached to the economizer. Referring to Fig. 47, it will be seen that there is a mechanical connection between the two carbons and a small electromagnet which operates the free carbon in order to strike the arc.

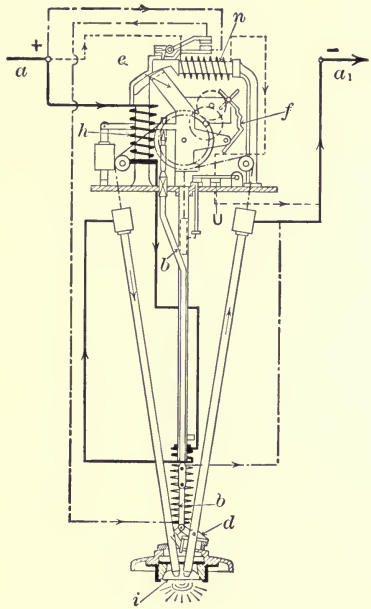


FIG. 50.—Clock Mechanism of Flaming Arc Lamp.

The gravity feed arrangement is also used in flaming arcs with clutch mechanism. The clutch performs the duty of gripping the carbon holder at the proper time, to prevent the carbon from sliding too far and holding it until the carbons are burned away enough for their resistance to be lowered sufficiently to weaken the magnet actuating the clutch, which then releases the carbons. The arrangement of the parts of a typical clutch mechanism is shown in Fig. 49. A very recent clutch mechanism uses a friction brake to limit the feed,

which acts upon a screw which would normally rotate under the influence of the weight of the downward-fed carbons.

The clock mechanism shown in Figs. 50 and 51 is almost similar to the clock mechanism of the earlier forms of plain carbon arc lamps. A frame *e* actuated by a shunt magnet releases a detent *f* which allows the carbons to feed down. The instant the carbons come in contact a current flows through the series coil which is energized and raises them again, and springs an arc, the length of which is kept proper by the opposing action of the series and shunt magnet.

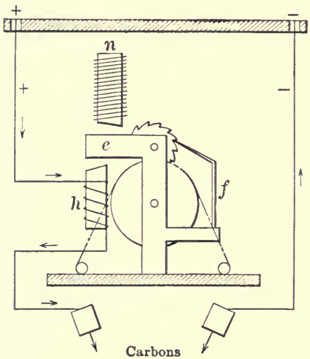


Fig. 51.—Detail of "Clock" Type Flaming Arc Lamp.

In Fig. 53 is shown the mechanism of the hot wire lamp, which utilizes the expansion and contraction of a wire to regulate the arc. A spring is arranged to oppose the hot wire to effect a balance, which, when the wire expands, contracts or *vice versa,* and imparts sufficient motion to the carbons to regulate the operation of the carbons. Lamps employing this mechanism can be operated equally as well on alternating as on direct current. The sluggishness of the action constitutes, however, a serious objection.

The motor-mechanism flaming arc lamp utilizes a metallic disk which is acted on by a differential magnet system (Fig. 52) and sets up a turning movement on the disk in either one or the other direction, or remains at a standstill, depending on whether the series or shunt coil predominates or one is balanced against the other.

Efficiency and Illuminating Characteristics of Flaming Arcs.—The intrinsic brilliancy of the flaming arc exceeds that of all other illuminants of the arc variety, and its light efficiency is much greater than that of the tungsten lamp. The specific consumption of energy per mean spherical candle-power is not over 0.5 watt per candle-power ("mean spherical"), which figure exceeds that of the enclosed carbon arc from four to six times, and is also nearly three times less than that of the tungsten lamp.

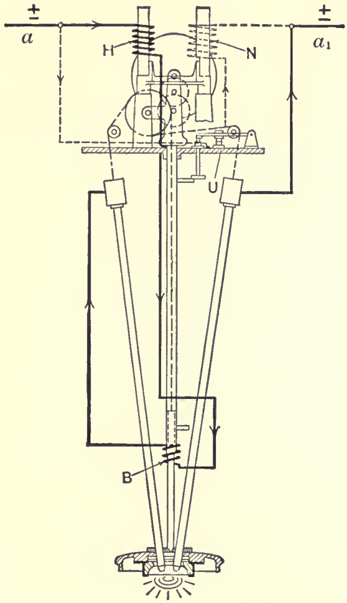


Fig. 52.—Mechanism of Motor Type Flame Lamp.

This high illuminating power is thrown exactly below the centre of the lamp which enables it to be utilized more efficiently for some purposes than is the case with arc lamps having vertically superposed carbons, which emit their maximum light intensity at an angle of 45 degrees below the horizontal. This concentrated illumination feature of the flaming arc is not a desirable quality when such lamps are used for street lighting, where the lamps are widely spaced, and it would be decidedly preferable if the light immediately under the lamp had a minimum intensity increasing with the angle from the vertical.

The reason for the high illuminating power below the

lamp is that light is not only emitted from the luminous vapor path, but the major portion of the light comes from the incandescent carbon tips. The idea has been prevalent that all the light of the flaming arc is emitted by the luminous vapor, but this is a fallacy, as Professor Wedding has shown that only about one-quarter of the light comes from the arc flame, the other three-quarters coming from the incandescent carbons. Since most flaming arc lamps employ an ash receiver, the effect of a maximum light intensity in the downward plane is modified by the obstruction which the receiver offers.

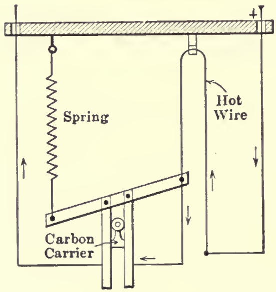


FIG. 53.—Mechanism of Hot Wire Flaming Arc.

The influence of the globe and ash receiver on the light distribution from the flaming arc is strikingly shown in curve II of Fig. 54, which is from a photometric test made by Mr. A. A. Wohlauer, Consulting Illuminating Engineer. Curve I of the same figure is the typical candle-power curve of the flaming arc lamp without globe or ash receiver, both curves having been made in a vertical plane through the axis of the two carbons. The figures at the top or on the horizontal line refer to the candle-power, while the figures below with the degree sign appended correspond to the angles at which the particular candle-powers are emitted. As is obvious from the inclined position of the carbons, the arc shape in these lamps is semicircular. This unsymmetry of the arc is, in practice, partially eliminated by the globe employed on the lamp.

Factors Influencing Economy of Flaming Arc Lamps.—Although, as previously stated, the intensity of light given

by the flaming arc increases with the percentage of the salts added, and the specific energy consumption is as low as 0.34 watt per mean spherical candle-power with carbons containing 40 per cent of "fluorspar" salts, still such a high proportion of metallic salts in the core is not practicable nor conducive to economy, due to the excessive formation of slag. The economy of the flaming arc lamp is also governed by the dimensions of the carbons. The diameter of the carbons is governed both by the kind of lamp and its construction, and is affected also by the kind

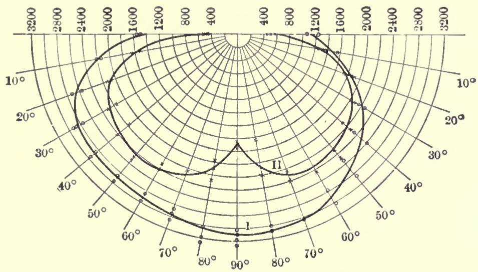


Fig. 54.—Curves Showing Influence of Globe and Receiver on Light Distribution of Flaming Arc.

of blow magnet and economizer used. The diameter must be limited, as has been mentioned, to obviate climbing of the arc. The economy of flaming arcs is hence limited by the lengths of the carbons which, of course, limits their life. Increasing the length of the carbons increases their life and hence reduces the expense of trimming.

The candle-power or size of the flaming arc lamp also governs its economy to a certain extent. Tests have shown that it is more economical to use one large unit than to obtain the same candle-power with a number of smaller ones, as the initial expense of multi-unit lamps is greater and the operating expense is decreased.

Summarizing the practical advantages and disadvantages of the flaming arc lamp, it may be stated that its first and foremost feature is a very high efficiency, exceeding greatly that of any other illuminant on the market. The chief disadvantages are the present high price of the carbons used on account of the high tariff imposed on their importation (nearly all the flaming arc electrodes come from Germany), the frequent trimming required, the fumes given off, the deposit of ash inside the lamp, and its unsuitability for street lighting.

Present-Day Field of Service of the Flaming Arc Lamp. —In our country the luminous or flaming arc has been in use only a few years and hence the number of applications which have been made of it are few as compared to its use in Europe, particularly Germany, where the lamp originated and is widely employed, its extraordinary efficiency appealing greatly to the thrifty Germans.

In Germany the lamp is extensively used for municipal street lighting and fairly satisfactory results are obtained, despite its unfavorable light emission for this purpose. The usual practice is to suspend the lamps from cables secured to the walls of houses on opposite sides of the street, the lamps being hung about 30 to 35 feet high in the centre of the streets and spaced up to 300 feet apart.

The lighting of squares and plazas is done by mounting three or four lamps about 50 feet high on ornamental poles. In this way the cost of installation is much reduced as only one pole and one set of cables are needed.

In German practice it is also the rule to use carbons of different lengths, depending on the season. Thus in winter when the nights are long the carbons are long, while in summer when the nights are short, their length is reduced. The strong feature of the lamp—cutting itself out of ser-

vice when the carbon is consumed—permits it to regulate easily.

In Continental Europe luminous arcs of one type or another dominate the field of outdoor lighting, since it has been the experience that the more light produced the more the public demands. For example, where two gas arcs were formerly used, four and occasionally six flaming arcs are used; and it is no unusual sight to count as many as 50 to 75 flaming arcs on one block in Berlin.

The possibilities of enhanced illumination by the use of the flaming arc have been quickly foreseen by industrial establishments of all kinds in both this country and abroad, and mills, foundries, machine shops, etc., report increased outputs and higher class of service as a result of its use. The immense volume of light which it produces permits the lamp to be suspended high enough to clear all machinery and yet illuminate the space below with powerful brilliancy.

The flaming arc is rapidly monopolizing the field of advertising by electric means. All kinds of amusement enterprises, parks, and theaters have realized the efficiency of the flaming arc for commanding attention, while the department stores of the large cities frequently utilize as many as 50 lamps of this type in front of their building, which does not fail to make it conspicuous.

Shopkeepers of all kinds are increasing the brightness of their show windows by employing flaming arcs, and at the same time are decreasing the first cost of lighting as well as operating expenses. For this purpose the lamps are mounted above the window, the ceiling of which is of opalescent glass. In this manner a powerful volume of light is cast in the window, the source of light being concealed. It has been found that when so used the yield of

light from a 550-watt flaming arc is equal to that of 2,000 watts in incandescent lamps.

In England the flaming arc has made but little progress, but the outlook for its widespread adoption is most favorable. In London the high penetrating power of the lamp has been found very serviceable during the famous fogs which prevail there.

The utilization of the flaming arc in France has also been slow, the principal use of the lamp having been made in lighting a few streets of Paris and the chief cities. As is the case in most European countries the most satisfactory lamps in use are of German make.

Influence of the Flaming Arc in Compelling Use of Tungsten Lamps.—For interior illumination—particularly stores—the flaming arc has exercised a peculiar influence in making the use of the tungsten lamp almost compulsory. It is customary for shopkeepers who appreciate the value of the flaming arc as an advertising medium to install one or two of these lamps in front of their stores.

The powerful brilliancy of the light causes the pupil of the eye to contract to such a degree that to the observer the illumination of the store appears defective; although in reality it may be excellent both in point of distribution of light and intensity of illumination. So great is the contrast that the storekeeper is obliged to use tungsten lamps in place of the ordinary incandescent lamps, and at the same time use more of them. In those cases where the flaming arc is used for advertising purposes, the shadows in the windows are offset by studding the roofs with 60-watt tungsten lamps in mirror reflectors. The intensely brilliant light of both the flaming arc and the tungsten lamp not only causes the light from the ordinary carbon filament lamp to appear dim, but also shows up the sickly

green light from the gas lamps and finally causes their displacement.

Maintenance Expense of Flaming Arcs.—The increasing use of the flaming arc for street lighting and for industrial plant illumination makes the question of their maintenance cost as compared with ordinary arcs of great consideration.

The energy consumption of the "differential" type of flaming arc is 550 watts, which, at an average cost of 2 cents per kilowatt-hour, makes the lamp consume $11 of energy per 1,000 hours for current. Taking the net cost of imported flaming arc carbons, the cost per trim per 1,000 hours, labor included, is $8.50, making the total cost of trim and carbons $19.50 per 1,000 hours. The cost of repairs and globes per 1,000 hours may be estimated at $2, to which must be added interest on the investment, while a depreciation of $2 per 1,000 hours must also be included; which totals $23.50 per 1,000 hours of operation as the maintenance cost. Estimating the average yearly burning as about 4,000 hours, the cost would be $94 per year per lamp.

Comparison of Cost of Operation of Ordinary Enclosed Arcs and Filament Arcs.—The figures given below apply to one of the leading flaming arcs illustrated and described in preceding pages, the name of which is withheld on the ground that the author may be considered unduly biased in its favor. As the most highly developed types of flaming arcs will approximate these figures, the values quoted may be accepted as a criterion of their economy of operation. In the basis for comparison, the assumption is made that four flaming arcs of this particular type, giving 3,000 mean hemispherical candle-power, will replace 16 ordinary enclosed arcs giving 500 candle-power each.

Sixteen Ordinary Arcs

CURRENT—	
16 lamps—660 watts—100 hours 1 cent per kilowatt	$10.56
CARBONS—	
16 lamps, at 3 cents per lamp, for 100 hours..............	.48
LABOR—	
16 lamps at $7\frac{1}{2}$ minutes per trim—or 2 hours at 25 cents....	.50
	$11.54

producing, assuming that the ordinary arcs give a full 500 candle-power = 16 lamps × 500 candle-power × 100 hours = 800,000 candle-power; and 800,000 candle-power is really what has been bought, which costs $11.54.

Four Highest Efficiency Flaming Arcs

CURRENT—	
4 lamps—550 watts—100 hours—1 cent per kilowatt.....	$2.20
CARBONS—	
4 lamps at 1 cent per hour..............................	4.00
LABOR—	
4 lamps—$7\frac{1}{2}$ minutes—6 trims	1.80
	$8.00

producing: 4 lamps × 3,000 candle-power × 100 hours equals 1,200,000 candle-power, which costs $8, as against 800,000 candle-power for $11.54 as furnished by the 16 ordinary enclosed arcs. On the basis of 1,200,000 candle-power for $8, 800,000 candle-power would cost $5.33 if furnished by the best flaming arc lamps, as against $11.54 when furnished by the ordinary arcs.

As to the area of illumination, on the basis of 785 square feet illuminated by one ordinary arc lamp, 16 lamps should therefore illuminate 12,560 square feet, and on the basis of 4,752 square feet illuminated by one excellent flaming arc lamp, four lamps would illuminate 19,008 square feet.

As noted above, the operation and maintenance of 16 ordinary enclosed arc lamps cost $11.54 for 100 hours at 1c. per

kw.; therefore, one lamp costs 72c. for the illumination of 785 square feet, assuming the lamps to be hung 16 feet high from the ground. On this basis the illumination of 1,000 square feet by enclosed arcs would cost 92c. for 100 hours.

The cost of operation and maintenance of 4 flaming arc lamps of a certain type for 100 hours being $8, as shown above, the maintenance of one lamp would be $2 to illuminate 4,752 square feet, or the equivalent of 42c. for 1,000 square feet for 100 hours, or less than half the cost of illumination by the ordinary enclosed arcs.

Where the substitution is made on the basis of 4 flaming arcs for 16 ordinary arcs, it will be seen that a saving in current is effected of over 8¼ kilowatt per hour, or nearly 80 per cent of the power consumption.

The difference in the cost of operation increases enormously with the increase in the cost of electric current.

The following table is a comparison of the cost of maintenance and operation of the ordinary enclosed arc lamps and the flaming arcs at various rates for electric current from 1 cent to 10 cents per kilowatt inclusive:

	1c. Per Kw.	2c. Per Kw.	3c. Per Kw.	4c. Per Kw.	5c. Per Kw.
Sixteen Ordinary Arcs	$10.56	$21.12	$31.68	$42.24	$52.80
	.48	.48	.48	.48	.48
	.50	.50	.50	.50	.50
	$11.54	$22.10	$32.66	$43.22	$53.78
Four Highest Type Flaming Arcs	$2.20	$4.40	$6.60	$8.80	$11.00
	4.00	4.00	4.00	4.00	4.00
	1.80	1.80	1.80	1.80	1.80
	$8.00	$10.20	$12.40	$14.60	$16.80

	6c. Per Kw.	7c. Per Kw.	8c. Per Kw.	9c. Per Kw.	10c. Per Kw.
Sixteen Ordinary Arcs	$63.36	$73.92	$84.48	$95.04	$105.60
	.48	.48	.48	.48	.48
	.50	.50	.50	.50	.50
	$64.34	$74.90	$85.46	$96.02	$106.58
Four Highest Type Flaming Arcs	$13.20	15.40	17.60	19.80	22.00
	4.00	4.00	4.00	4.00	4.00
	1.80	1.80	1.80	1.80	1.80
	$19.00	$21.20	$23.40	$25.60	$27.80

In the summer of 1909 exhaustive tests were made by the electrical commission of South Park, Chicago, on an installation of series flaming arcs. The installation comprises 11 lamps placed 100 feet apart and suspended 25 feet from the ground. With prismatic inner globes the maximum distribution of light is at 30° from the horizontal. The figures given below were submitted to the commissioners by the lamp makers to illustrate the relative cost of the cp.-year for various illuminants. (It is stated that the economy claimed for the flaming arcs has been very well borne out in operation.) The arbitrary figure of one cent per kw.-hour was assumed as the cost of electrical energy and the energy cost and cost of electrodes included, the proposition being then figured on a basis of equal illumination. The summary of these calculations is as follows:

1. 2,000-cp., direct-current, 9.61-amp., series flame arc lamp.—Watts (9.6 amp. × 47 volts), 451; kw.-hours per year (451 × 3.9), 1,759; cost of energy, $17.59; cost of electrodes, $37.43; total cost per lamp per year, $57.02; cost per candle-power per year, 2.75 cents.

2. 600-cp., direct-current, series open arc lamp.—Watts (9.6 amp. × 55 volts), 528; kw.-hours per year (528 × 3.9), 2,059; cost of energy, \$20.59; cost of electrodes, \$4.74; total cost, \$25.33; cost per candle-power per year, 4.22 cents.

Fig. 55.—General Electric Flaming Arc.

3. 300-cp., alternating-current, series enclosed arc lamp.—Volt-amperes (7.5 amp. × 78 volts), 585, or 497 watts at 85 per cent power factor; kw.-hours per year (497 × 3.9), 1,938; cost of energy, \$19.38; cost of electrodes, 86 cents; total cost, \$20.24; cost per candle-power per year, 6.75 cents.

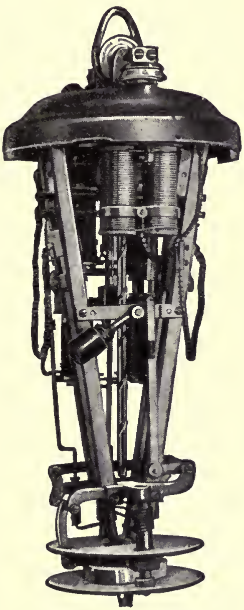


Fig. 56.—Mechanism of General Electric Flaming Arc.

4. 1,400-cp., alternating-current, series flame arc lamp.—Volt-amperes (7.5 amp. × 45 volts), 337.5, or 287 watts at 85 per cent power factor; kilowatt-hours per year (287 × 3.9), 1,119; cost of energy, \$11.19; cost of electrodes, \$33.84; total cost, \$45.03; cost per candle-power per year, 3.22 cents.

General Electric Flame Arc Lamp.—An assembled view of the flame arc lamp, made by the General Electric Company, is shown in Fig. 55. The frame of the lamp, which has an over-all length of only 31 inches, consists of four steel rods fastened to a top plate

of flat steel. The mechanism, which can be seen in the skeleton views (Figs. 56, 57, and 58), is of the differential type, and differs only in minor details from the usual essential components of such a mechanism as described on page 119. The economizer of the lamp is made of highly refractory material and has a protecting magnet to obviate damage to it from a high burning arc. The blowout magnet performs the function of not only blowing the arc downward into the proper position, but also automatically prevents it from creeping up into the economizer and causing burnouts or short circuits. The resistance for direct-current lamps is wound on grooved porcelain bobbins and placed, as can be seen in Fig. 57, in the frame of the lamp. No external resistance is employed when the lamp is operated two in series on 110-volt circuits, but when operated singly, a resistance mounted externally in a separate casing is used. For single operation the alternating-current lamp is equipped with a steadying resistance, mounted within the lamp casing and conducted in series with the "reactance."

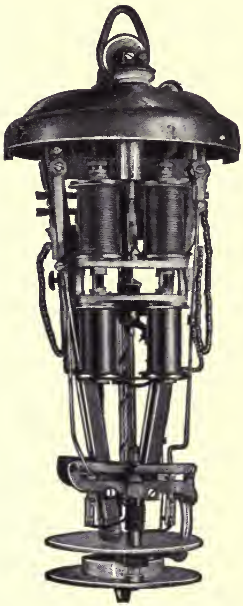


Fig. 57.—Mounting of Parts of Lamps Shown in Fig. 55.

The life of the lamp is ten to twelve hours with one set of approved flame carbons, the standard lamp being wound for a current of 12 amperes.

The Excello Flaming Arc is a German-made lamp mar-

keted in this country by The Excello Arc Lamp Company of New York. An assembled view of one type of Excello flaming arc is shown in Fig. 59.

The direct-current lamp-regulating mechanism is of the differentially wound escapement-wheel-feed type. (Fig. 52.) The two carbon holders are mechanically independent, but are operated simultaneously by the regulating mechanism. When the lamp is extinguished the carbons are separated. When the current is switched on, the shunt coil operates a simple device by which the carbons are drawn together until contact is made. Immediately on the passage of the full current the series coil acts on the regulating mechanism to draw the carbons apart, thus establishing and maintaining the arc at a practically constant value.

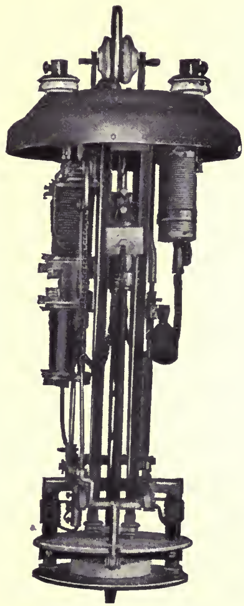


Fig. 58.—Another View of Lamp Shown in Fig. 55.

The regulating mechanism of the alternating-current lamp is of the differentially wound motor-feed type. When not in circuit the carbons are separated. When current is switched on, the rotor is rapidly revolved by the shunt magnets, thus lowering the carbons to their striking point. As soon as the carbons come in contact the series magnets operate the rotor in the reverse direction and the arc is drawn into the economizer, where it retains its proper position by the balancing influence of the two sets of magnets which control the rotor movement.

In order to avoid the possibility of the arc running up the carbons when they have fed down to the lowest point, an automatic extinguisher is provided. On lamps to be used in circuits up to 125 volts this extinguisher operates as follows: As the carbons reach nearly their lowest possible position the shunt circuit is automatically broken by a carbon switch mechanically operated by a small detent on the chain connecting the carbon holders. This causes the series magnet to separate the carbons as far as possible, thus extinguishing the arc.

Fig. 59.—Excello Flaming Arc Lamp.

When intended for use on d.-c. circuits of 220 volts and upward, the Excello lamp is fitted with a compound blowout magnet, which is partially excited by a series winding during the normal operation of the lamp, but is so arranged that at the moment of the breaking of the short circuit and the separation of the carbons which follows, an auxiliary winding is connected into circuit, which augments the magnetization of the blowout magnet to such an extent that it invariably suppresses the arc. For operation on circuits of 240 volts and upward the lamps are additionally protected by the employment of an automatic switch and a compensating resistance. Alternating-current lamps are not equipped with compound blowout magnets.

Alternating-current Excello lamps, when more than two are operated in series, are equipped with a safety coil connected in parallel with each lamp to obviate excessive voltage rises, the upper limit at which the lamps will automatically extinguish themselves being 125 volts.

The candle-power and light distribution of the Excello flaming arc lamp may be varied by the use of inner prismatic globes, or the contrary. For instance, the candle-power and the distribution of light when a prismatic inner globe is used, show a maximum candle-power of nearly 4,000 at an angle of 60 degrees from the vertical, making a spread of 120 degrees. This distribution is especially adapted for street lighting and for places where it is desirable to hang the lamps nearer to the ground.

On the other hand, the candle-power and light distribution when the prismatic inner globe is not used, show a maximum of 3,500 candle-power at an angle of 25 degrees and 3,000 candle-power at an angle of 45 degrees.

As 3,000 candle-power will give an illumination corresponding to a unit of about one foot-candle at a distance of 55 feet from the source of light, by referring to above data it will be seen that an Excello flaming arc lamp hung 38.89 feet from the ground will give that unit of illumination on the ground over a circle 77.78 feet in diameter, equal to 4,752 square feet. Of course, the lamps may be hung at any height desired, but the concrete example is given for the purpose of comparison.

The powerful brilliancy of this type of flaming arc is often utilized to illuminate the entrances to theatres and amusement places.

The Beck Flaming Arc Lamp, the invention of Heinrich Beck of Mittingen, Germany, and manufactured both in this country and abroad, is a gravity feed lamp.

The Beck lamp is designed to operate singly on 55 to 65 volts, and two in series on 110 to 120 volts, and four in series of 220 to 240 volts, on either direct or alternating current. The carbons burn from 8 to 15 hours, depending on their length, and consume 0.163 watt per hemispherical candle-power.

Jandus "Regenerative" Flame Arc Lamps.—This lamp, the invention of A. D. Jones, is radically different from the flaming arc lamp of usual design, in that it is an enclosed arc similar in this respect to the older types of ordinary carbon arc lamps. It has been pointed out that if the ordinary flaming arc lamp was enclosed, the fumes evolved from the chemically impregnated carbons would soon coat the globe with such a dense deposit as to obscure the arc. The two novel features of the lamp are the means for obtaining a circulation of the gases past the arc, and the method of producing the light, which consists in raising certain gases to the temperature of incandescence, and not by the combustion of chemicals as in the ordinary arc.

A diagrammatic view of the Jandus lamp is shown in Fig. 63. The lower carbon, which is the positive, is held in a fixed support. A clear glass cylinder surrounds the arc and outside this is a translucent globe. The inner glass cylinder communicates with two metal tubes, one on each side of the globe. The hot gases generated circulate up the central cylinder and down the other tubes, while the incandescent gases are carried around and subjected to the high temperature of the arc several times before finally condensing and settling in the outer tubes. As a result of the high temperature, chiefly, the inner glass cylinder is kept free of deposits for the greater part of its length, which prevents the gases from condensing, both by virtue

of the heat and also on account of the strong draft past the arc.

The upper negative carbon is an ordinary non-impregnated high-grade carbon, while the lower or positive carbon is also a high-grade carbon, but it is of star-shaped section. (Fig. 60.) A chemical composition, which is laid in the form of a paste, is put in the grooves between the light rays of the star. The rods are then baked, and the paste expands into the pores of the carbons and becomes firmly attached in the grooves. This composition is volatilized at the rate of about 15 grains per hour, the gases rising up from the positive crater through the arc. The life of a single pair of carbons is 70 hours. The color of the light is a yellow white, but modifications can be obtained by changing the character of the composition on the positive carbon.

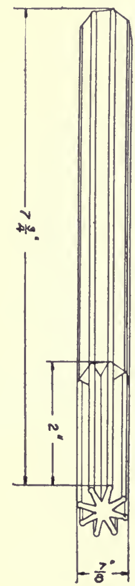


Fig. 60.—Positive Carbon of Jandus Lamp.

In Fig. 61 is shown a "polar" candle-power curve of the Jandus regenerative flaming arc, from which it is evident that the arrangement of the carbons and the enclosed globe gives a good distribution of light. The 550-watt lamp consumes 5.5 amperes at 100 volts, and produces a mean "hemispherical" candle-power of 2,200.

The Adams-Bagnall Regenerative Flame Arc Lamp is a very recent type of American flaming arc, which is shown in assembled form in Fig. 62. This lamp is a modified Jandus regenerative lamp.

The over-all length is 36 inches, and the weight about 40 pounds. The movement in both the multiple alternat-

ing- and the direct-current lamp consists of one coarse wire solenoid with an armature of special iron which is laminated in the alternating lamp; an equalizing lever, encircling the centre tube and pivoted on same, connected at its opposite end to dash-pot, which is rather larger than usual, and is equipped with a metal plunger, having a ball-and-socket connection to the stem. The clutch and lifting rods are of standard design.

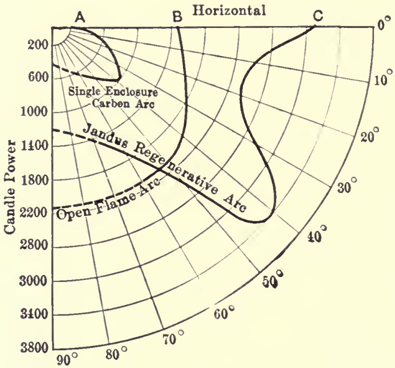


FIG. 61.—Polar Candle-power Curves of Regenerative Flame Arc.

In the alternating-current lamp a coil spring is interposed between armature and equalizing lever, to absorb current vibrations.

The connection to the upper carbon is made through a coiled flexible copper cable contained in the carbon tube. The lamp mechanism is enclosed in a heavy sheet-copper case and well protected from the weather, as well as from the gaseous products of the arc.

The gases pass into this through the top of the inner globe and, becoming heavier from cooling, fall to the bottom of the side tubes, at the same time depositing a large portion of the heavier elements on the tube walls and in the lower portion; the gases reenter the globe at the lower end and, being drawn upward by the heat of the arc, repeat the cycle of operation. Outside air cannot enter the inner globe, and only to a very limited extent the outer globe.

At the end of a 70-hour run there is a very slight efflorescence on the upper end only of the inner globe, but not sufficient to intercept the horizontal and downward rays or cause any perceptible dimming of the light.

The lamp is trimmed in a similar way to the ordinary carbon arc with closed-base inner and open-base outer globe. The lower, removable section of the circulating chamber serves as a base for the inner globe, and the two are removed together, as well as the lower carbon, which is held by a thumb-screw and clamp to the removable section. The outer globe remains in position.

Fig. 62.—Adams-Bagnall Flaming Arc.

The appearance of the arc of the regenerative flame lamp is shown in Fig. 64. As in the Jandus regenerative flame lamp, of which it is almost a prototype, the electrodes of the Adams-Bagnall lamp are placed vertically and in axial alignment, the lower being the positive and containing the light-producing salts, while the upper is almost of pure carbon. The composition of the lower electrode is similar to that used in other flame arcs, consisting of a structure of pure carbon in combination with calcium-fluorine salts. The central portion of the carbon is solid carbon with fluted or star-shaped sections, the spaces between ridges being filled to the outer edges with fluorine salts, giving the electrode the octagonal shape

shown in Fig. 64. The regenerative flame lamp retains the efflorescence of the carbons, which is discharged into an

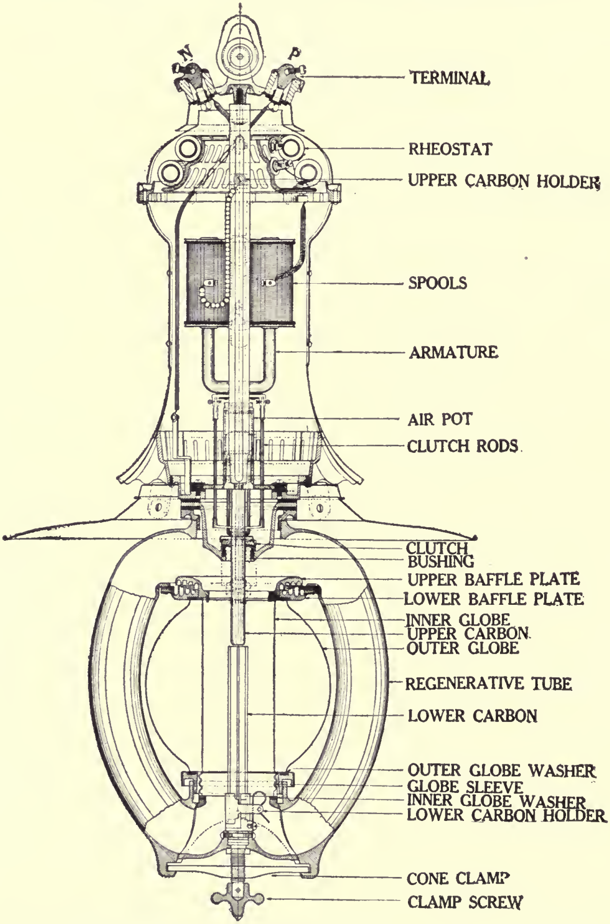


Fig. 63.—Diagrammatic View of Adams-Bagnall Type of Jandus Regenerative Flaming Arc.

upper chamber above the inner globe and from thence passes through side tubes to the bottom of the globe. The

passage of the gases through the side tubes lowers the temperature of the gases considerably, causing the less volatile elements to be deposited on the side walls, while the lighter gases return into the arc chamber, again mixing with the up-draft passing through the arc.

FIG. 64.—Arc Shape of Regenerative Flame Lamp.

In Fig. 65, which is a "photometric diagram" of a variety of types of arc lamps, taken from a paper by Mr. A. J. Mitchell, read before the Convention of the National Electric Light Association, June, 1909, the mean hemispherical candle-power of the Adams-Bagnall regenerative flame lamp is calculated as 1,340 with a consumption of 0.26 watt per candle.

Comparison of Economy of Regenerative Flame Arc Lamps over Ordinary Enclosed Arcs.—The following tables, prepared by Mr. A. J. Mitchell, may be considered a fairly approximate basis of the cost of carbons and maintenance of carbon arcs and flaming (regenerative) arcs, the lamps being operated both on street circuits burning 4,000 hours and on commercial circuits, burning 1,000 hours.

Street Arcs (500 Watts) Operated 4,000 Hours

	Two Enclosed Arcs	One Regenerative Lamp
Carbons	$2.68	$28.50
Trimming	2.34	1.28
Repairs	1.50	0.75
Inspection	0.90	0.45
Inner globes	0.60	0.30
Outer globes	0.30	0.15
	$8.50	$31.43

"It has been assumed in the above table that one regenerative lamp can replace two enclosed arcs. The cost of carbons for the regenerative has been estimated at 50 cents a trim, and for the enclosed arcs at 2.75 cents per trim.

Commercial Arcs (400 Watts) and Regenerative (350 Watts) Operated for 1,000 Hours

	Enclosed Arc	Regenerative
Carbons	$0.275	$7.12
Trimming	0.225	0.32
Repairs	0.75	0.75
Inspection	0.45	0.45
Inner globes	0.15	0.15
Outer globes	0.15	0.15
	$2.00	$8.94

"Assuming the cost of current at 2 cents per kilowatt-hour, the total cost for operating two series enclosed arcs (500 watts) for 4,000 hours would be $80 as against $30 for one regenerative (375 watts) lamp, and the total relative amounts for both maintenance and current, $88.50 and $61.43 respectively, showing a gain in favor of the regenerative lamp of $27.07, or figuring on the basis of lamp for lamp, a difference of $17.18 in favor of the enclosed arc; but the regenerative arc easily redeems itself in a comparison of costs per hemispherical candle-power.

Taking this at 1,340 gives 0.045 cent per hemispherical candle-power and 10 cents for the carbon arc, taking the candle-power at 440.

"In a comparison of values between lamps on the commercial circuit we have considered the actual consumption at the arc, current in both cases being 5 amperes and voltage of carbon arc 80 and of regenerative lamp 70. At 2 cents per kilowatt-hour the cost for 1,000 hours is $8 and

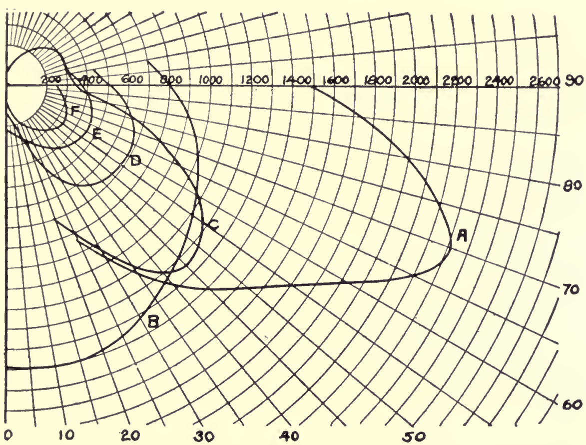
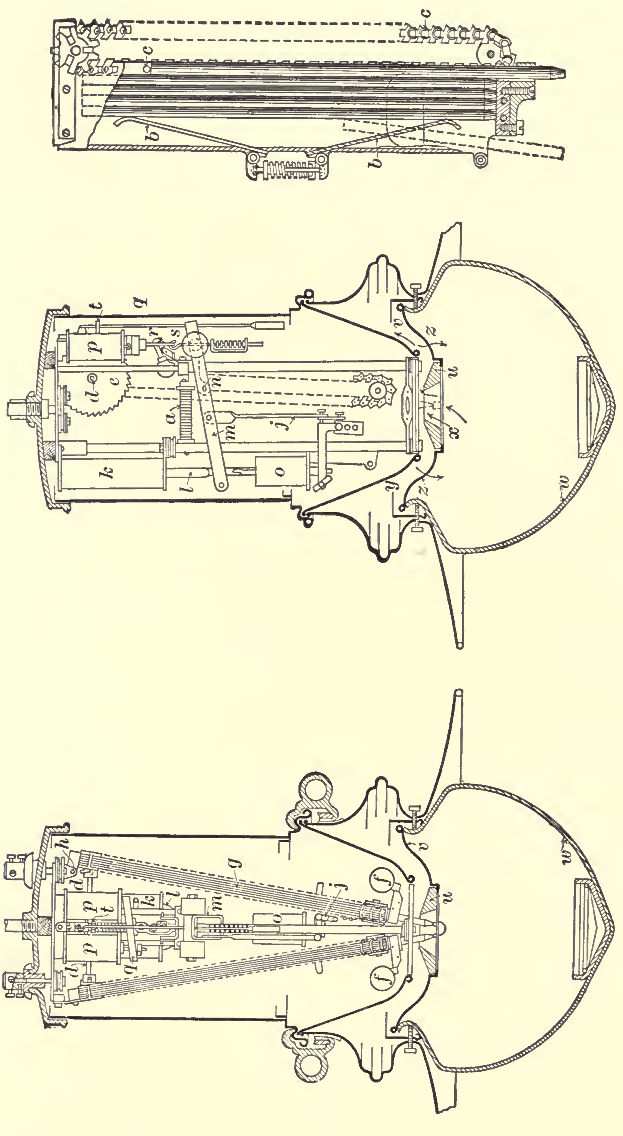


Fig. 65.—Polar Diagram of Various Types of Arc Lamps.

$7, respectively, or total costs for current and maintenance, $10 and $15.94 respectively; but where lamps are intended for interior use, and for such purposes as lighting mills, factories, halls, or for railroad stations, where a more or less concentrated light is preferable, the lamp can be fitted with suitable reflector, and, with a proper elevation above the floor line, one regenerative lamp will easily replace from three to four enclosed arcs and, on account of the penetrating nature of the ray, give more effective



a b c

FIG. 66.—Oriflame Magazine Flaming Arc Lamp.

illumination. Estimating conservatively and placing the ratio at 3 to 1, a saving of $14.06 per 1,000 hours is shown in favor of the regenerative lamp."

Multicarbon and Magazine Flaming Arc Lamps.—Attempts to produce flaming arcs of extraordinary brilliancy, with the added features of controlling the illuminating power throughout a considerable range, continuous operation so long as a single carbon remains in the lamp, and long life on one trimming, have resulted in various types of lamps employing many carbons connected in groups, and in the so-called *magazine* flaming arc lamps.

A type of magazine flaming arc lamp, known as the "oriflame" lamp, which is made in England, is illustrated in Fig. 66 a, b, and c. The magazine contains from six to nine pairs of electrodes, and by this means the lamp has a burning life of from 36 to 40 hours with each trim. The magazine for the negative electrodes is fixed, while that containing the positive electrodes is pivoted for the purpose of striking and regulating the arc. Each magazine is provided with an electrode feeding chain *c* and two chains are worked simultaneously from a toothed wheel *e*. The pawl engaging with this wheel is pulsated electrically by a small magnet, whose circuit is closed by means of a rocking mercury switch *r*. The rocking down of the electrodes occurs at regular intervals, and when a pair is burned out the ends are discharged into the globe and a new pair immediately comes into position. The changing of the electrodes requires about 20 seconds, the lamp during this time being extinguished. In the sectional views of the lamp (Figs. 66 b, and c) *k* is a differential controlling solenoid, which is one so wound that the two coils oppose each other in their action; *a* is the blowout magnet coil; *p b* the magnet working the ratchet feed; *g* is the magazine which is pivoted

and is moved by means of the rod *j*; *m* is the rocking arm; *f* is the counterweight on the loose piece of the electrode holder; *w* the fireclay plate through which the fumes from the arc escape, while *b b* are the levers pushing the electrodes forward, the spring for controlling which can be seen on the outside of the magazine. For direct-current service the "oriflame" lamp is made in three sizes, viz., for 7, 9, and 11 amperes, with a pressure of 34 volts across the terminals. On alternating-current circuits the lamps are used singly in connection with choking coils. The expense of electrodes is said to be as low as .22 cent per hour.

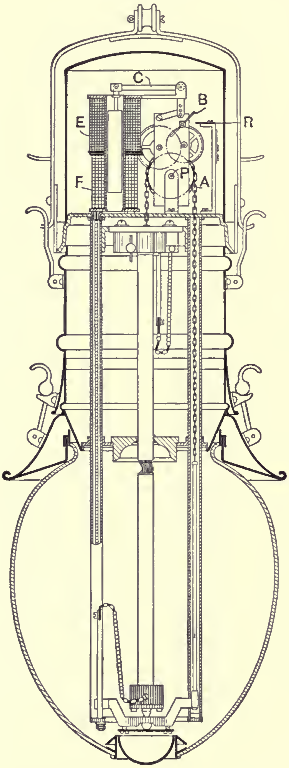


Fig. 67.—A Type of Vertical Electrode Flaming Arc Lamp.

Vertical Electrode Flaming Arc Lamps.—The necessity for arranging the carbons in flaming arc lamps in an inclined position has already been discussed on pages 114 and 115. The objection to the use of converging electrode lamps is that the maximum intensity of illumination is emitted in a downward plane. To remedy this, inventors have sought to produce a satisfactory flaming arc with vertically superposed carbons, so that a greater distribution of light would be emitted in a horizontal direction, thus

rendering the lamp particularly suitable for the lighting of streets and other open spaces.

One of the most recent of vertical carbon flaming arcs—the "Rebofa"—is shown in Fig. 67, which, it is claimed, operates quite satisfactorily. The lamp is equipped with gravity feed mechanism and with the usual shunt and series solenoid control of the arc. The two electrodes are connected by a chain passing over the sprocket wheel *A*, which is geared to a train of wheels terminating in a fan wheel *B*. The clockwork is pivoted on the axle *P* of the sprocket wheel, and the lever *C* of the regulating gear is connected by a system of smaller levers to the clockwork frame. When the arc lengthens the pressure increases and the shunt solenoid *E* raises the plunger and thus rocks the clockwork frame to the left. This action brings the two electrodes a little nearer together. As they burn away the clockwork is rocked still more to the left, and finally the fan wheel *B* is brought out of contact with the fixed clutch *R*. The mechanism is thus released and feeding occurs until the series coil draws a plunger down, again causing the fan wheel to be locked. An interesting point in connection with the air dash-pot provided, is that the piston is of graphite, thus obviating any tendency for it to stick. The length of arc on this lamp is quite short and the variation in the length is very small.

The feeding of the carbons takes place at very frequent intervals, but the electrodes are moved together but a slight distance at each feed.

The "economizer" of this type of lamp is of fire-clay, supported by a cast-iron ring. A blowout magnet is unnecessary with the Rebofa lamp. The electrodes employed are of special manufacture, with large impregnated cores surrounded by a comparatively thin shell of pure carbon.

On account of the arrangement of the electrodes the arc burns steadily from the cores, having no tendency to burn from the hard carbon shell. The light is a soft white and should prove good for giving true color values. Carbons giving yellow or pink light can also be used if desired.

A 34-inch, 12-ampere "Rebofa" lamp burns 18 hours on one pair of carbons, and a 40-inch, 12-ampere lamp burns about 25 hours.

The Magnetite Arc Lamp.—This type of lamp belongs to the luminous class of arc lamps, and is due chiefly to the investigations of Dr. C. P. Steinmetz, chief electrician of The General Electric Company. Its chief characteristics are long life of electrodes—approaching 200 hours on a single burning—light of great carrying capacity and good distribution, high intrinsic brilliancy with low energy consumption.

The arc derives its name from the fact that the negative electrode is composed chiefly of magnetic iron ore, with a certain percentage of titanium oxide added (TiO_2). The positive electrode is of copper, the size of which has but little effect on the behavior of the arc.

The magnetite arc differs radically from the ordinary carbon arc and also from the flaming arc, in that it can be operated only on direct-current circuits. It is also essential that the magnetite electrode should form the negative electrode, which is, as a rule, placed in the lower holder of the lamp. If magnetite is used for the positive as well as the negative electrode the arc falls off both in brilliancy and efficiency; and the positive electrode, which when metallic lasts 2,000 hours or more, is more rapidly consumed.

The bulk of the electrodes consist of magnetite, the

particles of which make the arc stream a good conductor, while the titanium oxide is introduced to give luminescence and to neutralize the excessive blue rays emitted by the iron arc alone. The use of magnetic iron ore and titanium oxide alone in the negative electrode, however, would make the arc too unstable for any commercial use; hence, to obviate this defect and at the same time increase the life of the electrodes, either oxide of chromium (Cr_2O_3) or chrome iron ore ($Fe_2Cr_2O_4$), termed chromite, is added, the latter perhaps being the most suitable. The slag formed by the magnetite is a good conductor when cold, so that difficulties in starting the arc are overcome. Ordinary magnetite contains too many impurities to be used, and contaminating substances, such as lime, silica, and magnesia must be first eliminated.

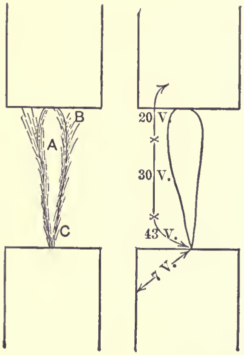


FIG. 68.—Shape of Magnetite Arc Flame.

The shape and general character of the composite arc are shown in Fig. 68. The centre is composed of a narrow band *A*; the brilliancy and thickness of which depends on the amount of titanium oxide present; the higher this percentage, the narrower this band becomes. The absence of titanium causes the central cone almost to disappear. The outer zone *B* is made up principally of fumes, and emits but little light; its importance increases with the percentage of magnetite used. The portion *C* of the cone is indicative of the quantity of chromium present.

The arc of the magnetite lamp appears to arise from the surface of the negative electrode as a high velocity blast impinging on the copper positive, and since the greater

portion of the light is emitted at the negative end of the vapor bridge, a reflector must be employed to give the most satisfactory results. It is obvious that considerable gain in efficiency is practicable by burning the arc reversed or with the negative electrode in the upper holder of the lamp. Until recently the mechanical difficulties to this arrangement caused it to receive small consideration, although the advantages were everywhere recognized. In the Westinghouse magnetite arc (Fig. 73), the negative electrode is in the upper instead of the lower portion of the lamp.

The arc of the magnetite lamp is very long and gives a better distribution of light than does the old open-arc carbon lamp, while the energy consumption is only 4 amperes at from 65 to 75 volts. The maximum light is emitted between 20 degrees and the horizontal, while a total light produced by a 300-watt magnetite arc is approximately double that of an alternating-current series-enclosed carbon lamp consuming 450 watts.

The principal disadvantages of the magnetite lamp may be briefly stated as follows and are due to the positive electrode in the main: (1) Continuous service of the lamp causes fumes to be deposited on the positive electrode, which deposits project downward like icicles and greatly obstruct or sometimes entirely cut off the light; (2) the substances employed in the positive may oxidize from the intense heat of the arc and form oxides, which, when cold, are insulators; (3) particles of molten matter are absorbed by the positive from the negative and the burning of the arc is thereby hindered.

Experience has shown that unless special means are provided for the ventilation of nearly all types of luminous or flaming arc lamps the solid matter emitted by the arcs

in the form of smoke is deposited upon the enclosing globe, forming a semi-opaque coating which is greatly detrimental to the light emission. Dr. C. P. Steinmetz has sought to obviate this by a patented arrangement shown in Fig. 69, in which the solid matter is directed away from the air-enclosing globe and is then removed or eliminated from the air currents which carry it.

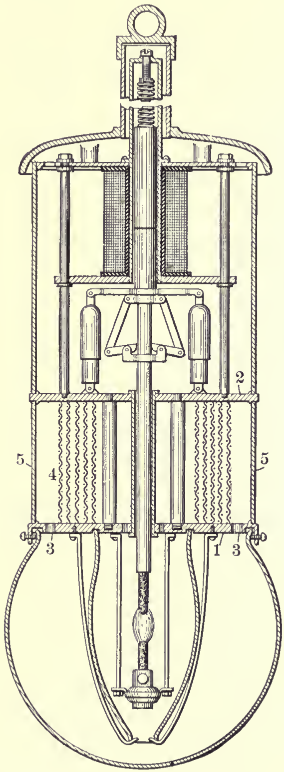


Fig. 69.—Steinmetz Ventilated Magnetite Arc.

The arc which is formed between the electrodes is surrounded by a small enclosing globe, open at its lower end as shown in the diagram (Fig. 69). The inside of this arc-enclosing globe is in communication with the interior of a chamber 4, formed between the plates 1 and 2 and the cylindrical casing 5, the communication being effected by means of a suitable number of openings in the lower plate. The arc-enclosing globe is in turn surrounded by a spherical or other suitably shaped outer globe. When the lamp is in operation the arc heats the air immediately surrounding it and this air ascends through a series of openings into the chamber formed between plates 1 and 2, thereby setting up a draft through the lower end of the inner air-enclosing globe. This draft causes air to be drawn from the cham-

ber 4 through suitable openings, some of which are indicated at 3, down into the outer globe. The action described causes a continuous circulation of air from the inner arc-enclosing globe up into the chamber 4; then down from the

Fig. 70.—General Electric Magnetite Arc Lamp.

chamber into the enclosing globe, and from thence into the inner enclosing globe, and so on. This directed circulation of heated air from the arc permits the removal of solid matter emitted from the arc almost as soon as it is pro-

duced, and for this purpose use is made of a series of screens formed of wire gauze of moderately small mesh, these screens being placed concentrically in the chamber 4. The solid matter given off by the arc is thus deposited in the screens, instead of on the arc-enclosing globe.

Types of Magnetite Arc Lamps.—The General Electric magnetite arc, which is shown in assembled form in Fig. 70, consists of a main frame made up of an iron tube which also serves as a chimney. The electrode box, which contains the upper or positive electrode, forms the lower part of the chimney.

The windings for operating the lamp comprise a pair of starting magnets, a series magnet, a shunt or cutout magnet, and a starting resistance. The mechanism is housed in a casing made of copper and is removable from the lamp frame by loosening a hand-screw. The lamp operates in the following manner:

When the lamp is on open circuit the electrodes are out of contact with each other, the lower electrode being at a fixed distance from the upper electrode. Closing of the circuit causes the current to energize the starting magnet, which attracts the armature which is attached to the lower electrode, and brings it in contact with the upper electrode. Current then flows through the series magnet by way of the connecting wire, which is energized to open the circuit of the starting magnet. This action permits the lower electrode to descend by gravity and to draw an arc. The lamp then burns with its lower electrode carrier resting on its stop and with the series magnet maintaining the cutout contact open.

The gradual consumption of the lower electrode causes the voltage across the arc to increase until a critical value is reached, whereupon the shunt magnet, which is connected

across the circuit, is energized enough to raise its armature and thus close the cutout contacts. Closure of these contacts places the starting magnets again in circuit, which raise the lower electrode and reëstablish an arc of the right length.

The luminous arc of the same company (General Electric) for use on constant voltage circuits is shown in Fig. 71, which is an interior view with globe removed. The positive electrode is a T-shaped drop-forging of copper, which is protected from oxidization by means of an iron sleeve, the copper end being left bare for the arc contact. The lower electrode of the lamp is an iron tube eleven-sixteenths of an inch in diameter and $5\frac{3}{4}$ inches in length and filled with a prepared composition. The position of the upper electrode, unlike that in the series luminous arc lamp, is movable, which provides a more desirable feature in multiple type lamps. Only an outer globe is necessary, this being fitted with a small ash pan in the base to catch the particles thrown off by the lower electrode. The enclosing globe is frosted at the base to neutralize shadows immediately below the lamp and to hide the ash pan from view.

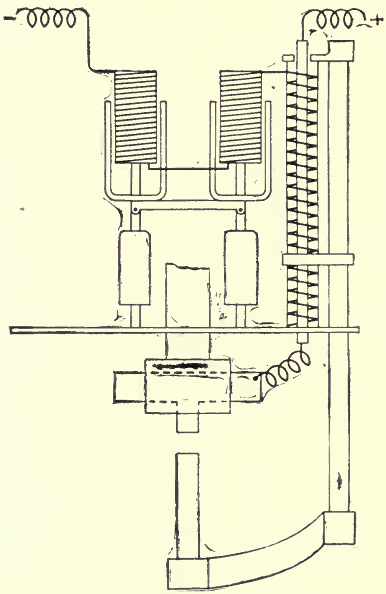


FIG. 71.—Internal Connections of General Electric Luminous Arc Lamp.

The multiple luminous arc is made for operation on standard 110-volt and 220-volt lighting or power circuits. The 110-volt lamp can be adjusted for any voltage from 100 to 125, the arc voltage being 73 volts and 4 or 5 amperes. The 220-volt lamp is similar in construction to the 110-volt lamp and operates on an arc voltage of 110

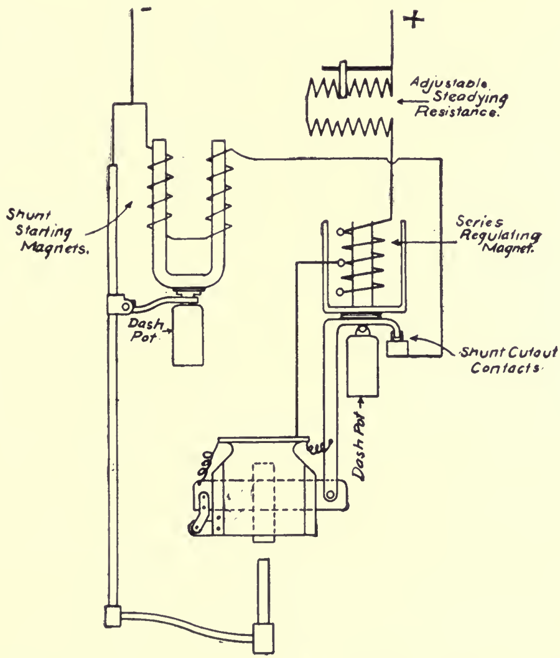


FIG. 72.—Internal Connections of Multiple Luminous Arc Lamp.

volts at 3 amperes. The diagram of connections of the multiple lamp is shown in Fig. 72, the simplicity of the connections being apparent. It will be seen that the only parts connected in circuit are the electrode, lifting magnets, and steadying resistance; these parts being connected directly in series. For power circuits this com-

pany makes a special type of luminous arc lamp, the construction of which is similar to that of the 110-volt lamp, except that a regulating weight has been added and operates directly on the E-shaped armature. The function of

FIG. 73.—Westinghouse Luminous Arc Complete.

the weight is to provide for variations in line and arc voltage and to oblige each lamp to take its own share of the available current continuously. This form of magnetite lamp is adapted only for multiple-series connection, the

lamps being operated two in series on 220 volts or five in series on 550 volts.

Illumination and Color of Magnetite Arc.—The spectrum of the magnetite arc with electrodes of correct composition approaches that of sunlight more nearly than that of any other kind of arc lamp, while the distribution of the light rays in a plane about 10° below the horizontal makes the lamp especially suitable for street illumination. The illumination curve of a 4-ampere series magnetite lamp is shown in Fig. 74. The specific consumption of a lamp of this amperage is 0.75 watt per candle.

The committee on Street Lighting of the National Electric Light Association presented at its annual convention in May, 1908, a report on the value of the magnetite arc for street lighting, and the table below, abstracted from their report, shows the remarkable illuminating value of the luminous arc. The values given below are based on the illumination at a distance of 150 feet from the lamp, each lamp being suspended 22 feet above the surface of the street.

Lamp	Value of X			
	Highest Lamp	Lowest Lamp	Average	Proposed Value
6.6 ampere, D.C. Series Enclosed Arc......	5	3	4	$3\frac{1}{2}$
9.6 ampere. D.C. Series Open Arc	$6\frac{1}{4}$	$3\frac{1}{2}$	$4\frac{3}{4}$	4
5.0 ampere, D.C. Series Enclosed Arc......	$4\frac{3}{4}$	$3\frac{3}{4}$	4	$3\frac{1}{2}$
6.6 ampere, D.C. Series Enclosed Arc......	$6\frac{1}{4}$	$4\frac{1}{4}$	5	4
5.5 ampere, A.C. Series Enclosed Arc	4	3	$3\frac{1}{2}$	3
6.6 ampere, A.C. Series Enclosed Arc	$4\frac{1}{2}$	$3\frac{1}{2}$	4	$3\frac{1}{2}$
7.5 ampere, A.C. Series Enclosed Arc	5	$3\frac{3}{4}$	$4\frac{1}{4}$	4
4.0 ampere, D.C. Series Luminous Lamp ..	7	7	5	$5\frac{1}{2}$

The unusual advantages of the magnetite arc, such as long life of electrodes, high luminous efficiency with low-maintenance expense, are resulting in the displacement of the enclosed-arc lamp for new installations and there are many indications that the magnetite arc will supplant the older types of arcs for street lighting entirely.

Magnetite lamps operate most satisfactorily on direct-current circuits as has been pointed out, the lamps being connected in series and receiving energy either from a constant-current arc dynamo or from alternating-current

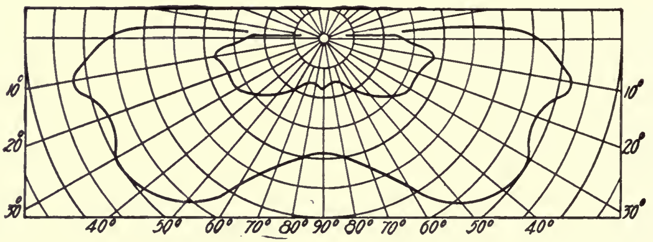


FIG. 74.—Photometric Curve Showing Distribution of Luminous Arc.

circuits, the current being transformed into direct current by means of "mercury rectifiers." The alternating current to be rectified is first sent through a repulsion-coil regulating transformer (or constant-current transformer), and then goes through the rectifier to the lamps. The combined efficiency of the constant-current transformer and mercury rectifier is over 90 per cent.

The chief objections to the luminous arcs as made at present is that the attempt to specialize the lamps in the direction of long life has resulted in its failure in other desirable qualities. It is very difficult to obtain authoritative values for these arcs, for the reason that until very

recently they were designed entirely for low input and have been generally tested with clear globes.

The powerful and uniform distribution of light from a magnetite arc is clearly shown in the street scene (Fig. 75).

The magnetic type of luminous-arc lamp thus has the advantage of giving a uniform distribution of light in a horizontal plane, a feature which was

FIG. 75.—Street Lighted by Magnetite Arc Lamps.

pointed out by Mr. Louis Friedman, in a paper read before the Missouri Electric, Gas, Street Railway and Water Works Association convention, Jefferson City, April 14, 1910.

Comparing the illumination given by various types of lamps, Mr. Friedman exhibited the following table of luminometer values, which, he said, represented the distances at which the same intensities of light were observed:

Open arc, 9.6 amp., direct-current; 285 ft.
Open arc, 6.6 amp., direct-current; 216 ft.
Enclosed arc, 6.6 amp., direct-current; 257 ft.
Enclosed arc, 7.5 amp., alternating current; 247 ft.
Enclosed arc, 6.6 amp., alternating current; 227 ft.
Luminous arc, 4 amp., direct-current; 327 ft.
Luminous arc, 6.6 amp., direct-current; 510 ft.

The comparative operating costs of these lamp per year of 4,000 hours was given by Mr. Friedman as follows, exclusive of overhead charges, which, he said, should be practically the same for all systems. These cost figures are based upon a 100-lamp installation, or over.

	Open-Arc, 9.6-Amp., D.C.	Open-Arc, 6.6-Amp., D.C.	Enclosed Arc, 6.6-Amp., D.C.	Enclosed Arc, 7.5-Amp., D.C.	Enclosed Arc, 6.6-Amp., A.C.	Luminous Arc, 4 Amp., D.C.	Luminous Arc, 6.4 Amp., D.C.
Energy at 1.5 cents per kw. hr.	$50.00	$32.70	$42.90	$34.50	$30.30	$38.82	$22.80
Electrodes.......	5.50	5.50	1.20	1.50	1.20	2.80	1.55
Trimming	6.00	6.00	2.00	2.00	2.00	2.05	1.00
Repairs	2.50	2.50	1.00	1.00	1.00	.75	.75
Inner globes	......	......	.45	.45	.45	......	......
Outer globes	.30	.30	.30	.30	.30	.50	.50
Renewals in Station equipment.	1.50	1.50	1.50	......	......	3.00	2.00
	$65.80	$48.50	$49.35	$39.75	$35.25	$47.92	$28.60

The Titanium-Carbide Arc.—The superior illuminating properties of the magnetite arc, having been found to be due chiefly to the titanium contained in the negative electrode, a great deal of experimental work has been done, in recent months, by the illuminating engineers of the General Electric and Westinghouse companies toward the development of a practical titanium arc. Experi-

mental installations of the titanium-carbide arc have been operated for considerable periods by both companies, and, while such lamps have neither been commercially standardized or placed on the general market, the steady advance in their perfection augurs well for the success of titanium arcs in commercial service. At the present writing there are in operation three important installations of titanium-

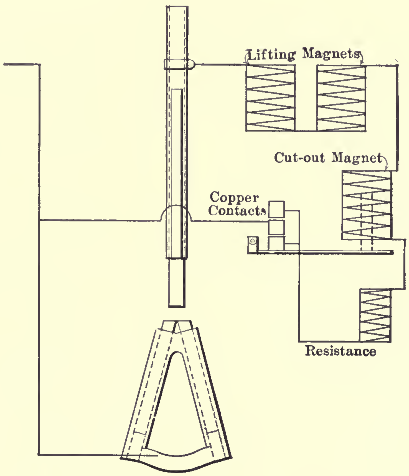


Fig. 76.—Mechanism of Titanium-Carbide Arc Lamp.

carbide arcs, consisting of 150 lamps at Rochester, N. Y.; 100 lamps at Schenectady, N. Y., and 250 lamps at Haverhill, Mass.

Tests conducted on the above-mentioned equipments have shown these lamps to possess the following characteristics: A specific energy consumption approaching 0.33 watt per mean horizontal candle-power, which value is about 25 per cent lower than that of the 4-ampere magnetite arc. Their power factor is low, being about 55 per

cent, due to the reactance required in the circuit to steady the arc. Such lamps operate on alternating current as well as on direct current.

A diagram of a characteristic titanium-carbide arc lamp mechanism and its connections is shown in Fig. 76. The titanium-carbide lamp system comprises a plain series lamp without a shunt winding, an oil-switch in series in the circuit, automatically opened and closed by a clock-control relay at suitable feeding intervals, and lastly a constant-current transformer through which the system is fed.

Referring to Fig. 76, the lamp mechanism will be seen to consist of two series magnets which, by means of a clutch, raise the upper electrode to obtain the proper arc length, whence it is held, the arc burning until the station relay momentarily opens the oil-switch, interrupting the current through the entire series circuit and permitting the upper electrodes to drop. The oil-switch then closes, completing the circuit to the lamps, and again springing the arc.

The electrodes of the titanium arc are three in number (Fig. 76), the upper or positive being composed principally of titanium carbide, about 12 inches long and 0.4 inch in diameter. The two lower electrodes are of carbon, six inches in length and 0.4 inch in diameter and are supported in an inverted "V" position with their upper tips abutting, and presenting a circular flat surface toward the upper electrode. The upper tips of the lower electrodes are kept in contact by a metal finger pressing upward beneath the electrodes as the latter burn away. The lamps are operated on 2.5 amperes, but 3- and 4.5-ampere lamps are in production.

As a protection against excessive potential the lamp is shunted with a suitable spark-gap in series with a resist-

ance and a cutout magnet, which short-circuits the gap. For instance, when the potential across the lamp is in excess of the break-down point of the spark-gap, current flows across the gap through the resistance and the cutout magnet, whose core, linked to one terminal of the gap,

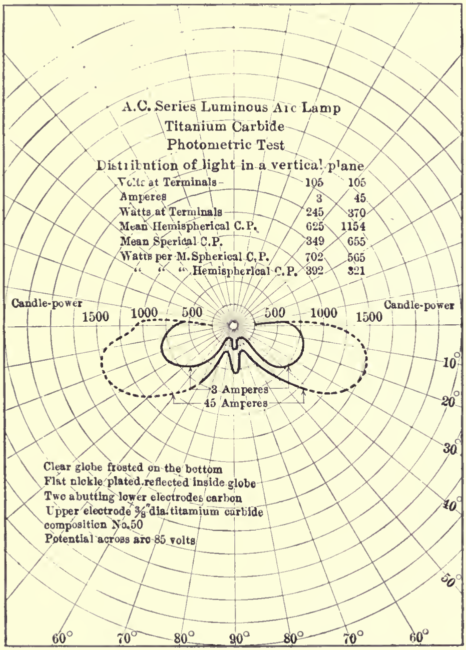


FIG. 77.—Photometric Curves of Titanium-Carbide Arc Lamp.

rises, thus short-circuiting the gap through the resistance and decreasing the voltage across the lamp terminals. Present types of titanium-carbide arcs are enclosed in a single clear globe, having a perforated base to afford sufficient ventilation and to carry away the fumes and the condensed vapor.

Characteristics of the Titanium-Carbide Arc.—The lamps of this type, so far developed, possess the characteristics given below:

Amperes	3	4.5
Volts at terminals	105	105
Power factor	78–80	78–80
Watts	245	370
Mean horizontal candle-power	624	1,154
Watts per mean horizontal candle-power	0.392	0.321
Mean spherical candle-power	349	655
Watts per mean spherical candle-power	0.702	0.565

The life of the electrodes of these lamps is about 75 and 50 hours, respectively, for the two sizes of lamps.

The efficiency of a titanium-carbide lighting system is from 95 to 97 per cent, and shows a power factor of from 50 to 60 per cent at full load when operating on 60-cycle current.

Operating Cost of Titanium-Carbide Arcs.—The figures given below are supplied by the manufacturers and apply to the alternating-current titanium-carbide arc in comparison with the magnetite arc.

	3 Amp. A.-C. Lum. Lamp	4 Amp. Lum. D.-C. Lamp Rectifier	4.5 A.-C. Lum.	D.-C. Lum. Rectifier
Energy at switchb'd, at 1c. per kw. hour	$11.28	$14.08	$17.00	$21.48
Electrodes	10.80	1.70	16.00	3.75
Trimming	2.40	1.00	3.50	2.30
Repairs	.75	.50	.75	.60
Globes	.50	.50	.50	.50
Rectifiers tubes		2.00		3.00

Shortcomings of Titanium-Carbide Arcs.—Aside from their relatively high specific energy consumption, as com-

pared with the magnetite arc, the cost of operation of the titanium-carbide arc is high, being about 20 cents per trim. The color value of the lamp is somewhat objectionable, being too yellow. The operation of the arc is also not very stable. A source of danger is the liability of the slag, condensed on the globe from the vapor of the arc, fusing into the globe.

A photometric curve of the candle-power distribution of a series titanium-carbide arc, from a paper presented by Mr. C. R. McCay, before the Ohio Electric Light Association, is shown in Fig. 77.

The present development of the titanium-carbide arc lamp is along the lines of having it supplement the magnetite and flaming arcs rather than competing with them.

These lamps are operated from a constant-current transformer which is similar to the well-known type used for the series-enclosed-arc system, and with 100-lamp units two series circuits are employed.

The function of the oil-switch used on the system is periodically and instantaneously to break the lamp circuit, thus discharging the duty generally performed by individual lamp-feeding mechanism. This oil-switch is operated by a 110-volt alternating relay circuit, opened and closed at proper intervals by a time clock. The relay apparatus comprises an induction-motor element which operates a contact finger corresponding to each relay circuit, each separate equipment having one such relay circuit and oil-switch.

CHAPTER V

VAPOR LAMPS

The Mercury Vapor Lamp is the earliest form of vapor electric lamp, having had its inception in 1860; but as it exists in present form is due to the researches of Dr. Peter Cooper Hewitt, who placed the lamp on a commercial basis, when he discovered that economical operation can be obtained only by a careful regulation of the temperature and density of mercury vapor. The luminous part of the lamp consists of a glass tube from which air has been exhausted, one end of which is made in the form of an oval and filled with mercury. Platinum terminals are sealed in each end of the tube for admitting electric current, the passage of which vaporizes the mercury into a stream of high conductivity. The conducting vapor is said to be "ionized" by the current, the two kinds of "ions" being termed, according to the terminal at which they are evolved, positive and negative ions. Luminosity of the lamp is produced by the incandescent particles in the vapor stream, the hypothesis being that the high temperature of the infinitesimal particles is due to the collision of the positive and negative ions travelling at enormously high speed. Although the temperature of the particles of matter in the tube is prodigiously high, the particles are so minute that the ultimate temperature of the lamp is reasonably low. Measurements of the Cooper-Hewitt lamp have shown the temperature to be 148 degrees centigrade at the positive and 164 degrees centigrade at the

negative terminal, the temperature at a point midway between the electrodes being 179 degrees.

In Fig. 78 is shown one of the latest forms of the Cooper-Hewitt mercury vapor lamp, the lamps being manufactured for both direct and alternating current. Referring to the figure (78), the complete lamp outfit is seen to consist of the glass vacuum tube, the holder, and the reflector. The tubes of direct-current lamps have a positive electrode of iron at one end, and a negative electrode of metallic mercury in a bulb at the other end. The tubes of the alternating-current lamps have two positive electrodes

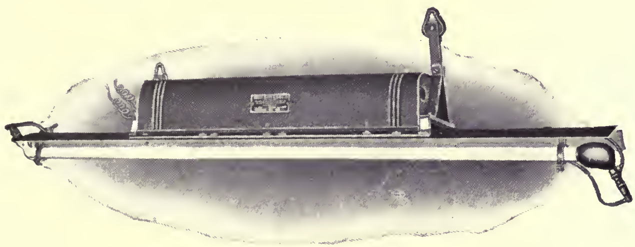


Fig. 78.—Cooper-Hewitt Lamp.

of iron at one end and a negative electrode of mercury at the other end, the alternating current entering the vacuum tube by the positive electrode and leaving by the negative electrode.

The complete auxiliary for alternating-current lamps comprises two or three coils of resistance wire, an inductance coil, and usually a "ballast" bulb to take care of voltage variations, all connected in series with the tube and enclosed under a metal canopy, which is fastened to the ceiling above the lamp on a plate attachment. The ballast bulb is designed to protect the lamps economically against undue voltage by means of a fine iron wire mount-

ed in a small glass globe somewhat resembling a miniature incandescent globe, the enclosing atmosphere being an inert gas which will not oxidize the wire. This iron wire possesses the peculiar property of increasing its resistance very rapidly as its temperature increases, so that a lamp protected by the ballast operates satisfactorily through a considerable range of voltage. The alternating-current auxiliary without casing is shown in Fig. 79.

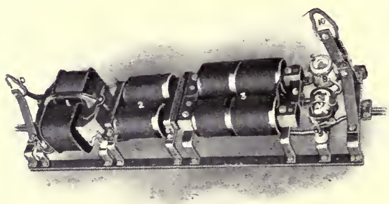


FIG. 79.—Regulating Mechanism of Cooper-Hewitt Lamp.

Characteristics of Cooper-Hewitt Lamps.—These lamps possess singular and interesting features. When the lamp is in operation there is a constant drop in voltage across the tube of about 25 volts for tubes of one inch in diameter, which, considering the length of the tubes, is insignificant. This drop in voltage is not made up of the resistance which all conductors offer to the passage of electric current, but is divided between the vapor stream and the positive and negative electrodes.

The current enters the mercury electrode at a small bright spot, vacillates over its surface and depresses the height of the mercury, wherever it happens to be. The placing of a metallic substance in the mercury will, however, cause it to be projected to its highest point and remain there.

With little resistance in series with it, the mercury lamp is very unstable on fluctuating voltage. To provide for this shortcoming a special device termed the ballast, which has already been mentioned, is used, being placed

in series with the tube and causes the lamp to work satisfactorily upon ordinary circuits.

In starting the lamp the tube is tilted until the mercury makes electrical connection between the electrodes; this is done either by hand or by some automatic means. Another method of starting the lamp is to cause a spark to pass through the tube by means of a high-voltage induction

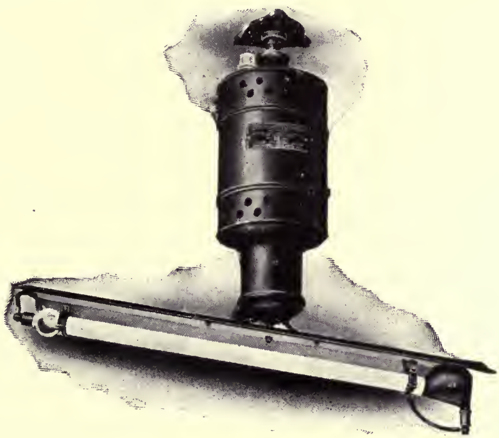


FIG. 80.—Cooper-Hewitt Automatic Tilting Lamp.

coil. The spark causes a rupture of the medium and the current immediately follows.

With the direct-current lamp an electromotive force of 25 volts will maintain an arc several inches in length, but to establish the same length of arc with alternating current, a pressure of several thousand volts is necessary.

Standard types of Cooper-Hewitt lamps are made with luminous tubes of from $17\frac{1}{2}$ to 50 inches in length. The operating economy of the lamps ranges from .55 to .64 watt per candle-power, which is one-sixth of the power

consumed by the carbon incandescent lamp, and about one-half that of the tungsten lamp. The operating life of the tubes averages 5,000 hours, while in individual cases the tubes have been known to burn 10,000 hours. The tubes cost about one-third of the total cost of the lamps, and are readily renewed when blackened from use.

The more or less serious problem of starting the so-called "tilting" mercury vapor lamp, as in cases where the lamps are suspended at considerable height, or where for other reasons it is impracticable for the operator to tilt each lamp, has resulted in the development of the automatic mercury lamp, which is illustrated in Fig. 80. The tube is the standard Cooper-Hewitt type, provided with the usual condensing chamber at one end and an iron positive electrode at the other end. All the auxiliary apparatus is contained in a compact round housing from which the tube holder is suspended.

The tube, which is 50 inches long, is entirely stationary and is subjected to no motion to effect starting. The initial discharge of current is brought about by applying a relatively high electric pressure across the tube terminals, which breaks down the starting resistance and causes current at the supply voltage to flow through the tube. The high pressure is created by interrupting the current through an inductance coil in series with the lamp, by means of a quick-break mercury switch, termed the shifter. This is connected in series with a starting resistance across the tube terminals as shown in Fig. 81 (the + and — signs referring to the positive and negative terminals, respectively, of the tube). Referring to the figure (81), the lamp is switched into circuit through the inductance coil, the shifter, the starting resistance, and the series resistance. The inductance coil operates an armature which causes

the shifter to break connection and open the starting circuit. The inductance effect sets up a high pressure across the tube terminals sufficient to break down the starting resistance of the tube. The arrangement of the parts of the automatic mercury lamp is shown in Fig. 81.

The shifter, which can be seen in the foreground at the bottom, is a small glass bulb about two inches long, provided with a V-shaped indentation forming a partial partition and

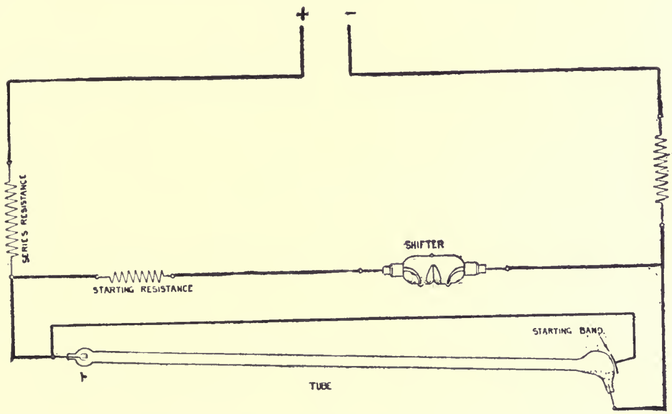


FIG. 81.—Connections of Automatic Lamp. Started by the Shifter Method.

tending to separate the mercury into two puddles forming the electrodes. To each one of these puddles leads a small platinum wire, making connections with suitable terminals. When the circuit is closed the shifter is in such a position that the mercury forms a bridge connecting the two leading-in wires together. The shifter is then turned upon its longitudinal axis by the action of the armature, and the partition divides the mass of mercury into two separate parts, thus breaking the electrical connection. When the mercury bridge is thus severed, the shifter

operates for a moment as a small mercury vapor lamp started on the tilting-lamp principle. The starting resistance, however, limits the current to a small value, hence the shifter lights for a brief interval and is then extinguished. The quick interruption of current creates the high pressure as stated, and current flows through the tube which comes up to full candle-power.

Color and Commercial Uses of Cooper-Hewitt Lamps.— The spectrum of the mercury vapor lamp is made up almost entirely of blue, green and yellow rays, red rays being

FIG. 82.—Interior of Silk Mill Lighted by Cooper-Hewitt Lamps.

entirely absent. Hence any colors containing red shades are more or less distorted, as, for instance, the lips of a person exposed to the rays of the mercury vapor lamp, appear ghastly green. On the other hand, green or blue tints are intensified. Only black and white are normally illuminated. It is thus apparent that the mercury vapor lamp has a restricted sphere of service, as its distortion of certain shades prohibits its use where true color values are required. Despite its shortcomings, however, the mercury vapor lamp has come into a wide commercial prominence during the past few years in many interesting and important installations in the field of industrial lighting. A very desirable feature of the lamp is its penetrating

power or the ability which it gives to distinguish details at a considerable distance. The color of the light is very easy on the eyes, and this has caused its adoption in drafting rooms and offices and also for certain kinds of decorative lighting.

The peculiar merits of mercury vapor illumination are even diffusion of the light from a luminous surface of great length, which prevents the formation of sharply-defined lights and shadows, or the contraction of the pupil of the eye caused by the concentrated luminous points of other lamps; and the freedom of the mercury spectrum from red rays, which extended physiological tests have shown to be the chief cause of eye fatigue in work under other artificial illuminants.

Light is emitted in uniform intensity from every portion of the tubes, and there are no dazzling or bright moving spots.

The chief field of usefulness of the mercury vapor lamp is in a certain class of industrial lighting, where the accurate determination of color values is not necessary. In recent years the Cooper-Hewitt lamp has been extensively adopted for the lighting of large machine shops and foundries; in business offices; in the press and composing rooms of many large publishing houses; in railroad repair shops; in pier sheds and freight houses; in textile mills; in automobile garages and shops; in piano and organ factories; leather and paper mills; glass and rubber factories; copper and sugar refineries, hat factories; navy yards and in wood-working plants. Fig. 82 shows the appearance of a large warping-room in a silk mill illuminated by Cooper-Hewitt lamps.

The high economy of the Cooper-Hewitt mercury vapor lamp is clearly shown by the following statements and

table. The type of Cooper-Hewitt lamp, having an approximate rating of 700 candle-power, operating upon 110 volts, consumes 3.5 amperes or 385 watts. At 10 cents per kilowatt-hour, the cost of energy is $0.0385 per hour. The average 16-cp. incandescent lamp consumes 60 watts, costing 0.6 of a cent per hour.

In a plant formerly using from 200 to 250 16-cp. incandescent lamps, 20 300-cp. mercury vapor lamps were installed. A comparison is interesting:

	Light	Power
200 16-cp. incandescents	..3,200 cp.	12 kilowatts
20 type H Cooper-Hewitts	6,000 cp.	3.85 "

3,200-cp. incandescents....	$1.20 per hour
6,000-cp. vapor lamps	.385 " "

Or an illumination from the mercury lamps equivalent to double the candle-power of the former illumination at one-third the cost.

The Quartz Mercury Vapor Lamp is a specialized form of mercury vapor lamp in which fused quartz is employed as a tube to withstand the very high temperatures at which the lamp operates. The vapor pressure at which the quartz lamp operates is about one atmosphere, the consumption of energy being about 0.25 watts per candle-power, measured perpendicular to the axis of the tube. The arc in the quartz lamp is very much shorter than in the low-pressure mercury lamps, and as a result the dimensions of the tube required are small, so that it is practicable to place it in a case and globe so as to resemble an arc lamp. Most of the quartz lamps at present are made for operation at voltages of 220 and 110 volts, and are designed for currents of 2.5 to 4 amperes. Thus far (1910) the quartz lamp has been used only in Germany, chiefly for display purposes in very much the same manner in which

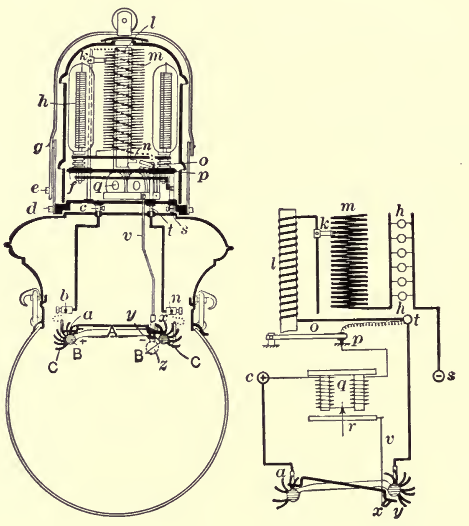
flaming arcs were at first used in this country. The properties of the lamp, however, are such that it is not unlikely that in time it will be seriously considered for general outdoor lighting.

The quartz lamp is simply an intense mercury arc, mercury vapor being forced to high temperatures and powerful luminous intensity by concentration in a working tube of barely more than capillary dimensions. For instance, the luminous tube of one of the latest types of quartz lamps is about the size of an ordinary lead pencil and emits from 1,200 to 3,000 hefner-candles with an energy consumption of about one-quarter watt per candle. This consumption of energy is that of the voltage at the tube terminals, which is about 85 for 100 to 130 volts of supply and 160 to 180 for double this voltage. Hence the efficiency based on the voltage of supply, including ballast, is not quite as good, being about 0.37 watt per candle, which however, compares very favorably with that of the flaming arc.

The life of the quartz tubes used in the most recent lamps is said to be from 2,000 to 3,000 hours, but at times running from 5,000 to 6,000 hours. At this writing all of the quartz used in these lamps is made by a single manufacturer, and naturally this situation leads to both high initial cost and limited quantities. The manufacture of quartz glass is so difficult an art that the output for this, as well as for other industrial purposes, is much restricted. This is due to the fact that molten quartz obtained at the highest temperatures is never fluid, but always more or less pasty, and hence liable to cause trouble due to the formation of bubbles. The technology of quartz-making will perhaps in time be vastly improved and will be in a number of manufacturers' hands.

The color of the light produced by the quartz lamp is much better than that of the ordinary mercury arc, the spectrum, though, being badly deficient in red. For outdoor lighting this shortcoming is not serious.

The Küch Quartz Lamp, shown in Fig. 83 a and b, is one of the most highly developed lamps of this type yet pro-



a b

Fig. 83.—Küch Quartz Mercury Vapor Lamp.

duced. The mechanism of the lamp is used only for starting and not for regulating the lamp, and hence is of simple design. The quartz tube *A* has at each end a closed cylindrical vessel *B*, filled with mercury. *C C* are metallic tubes for cooling the lamp at the ends. The quartz tube is supported on its axle *a x*, in bearings. The lever *v* connects the tube to the armature *r* of a shunt magnet *q*. When the circuit is closed, the armature of the shunt mag-

net is attracted, and the quartz tube so tilted that the mercury flows over from the upper end to the lower end and closes the circuit. Current then passes through the mercury in the tube. This current energizes the induction coil *l* which attracts its armature *o*, and thereby opens the circuit of the tilting magnet *q* at *p*. The quartz tube then returns into its original position; the mercury again separates into two parts, and the arc is formed.

The method of starting closely resembles the starting of an arc lamp in which the two carbons are first brought into contact and then separated from each other. In the quartz tube the arc will not maintain itself if the tube contains air. The arc will hence be broken, the tilting mechanism will again come into action, a new arc will be set up and more mercury evaporated; this action occurring only if the quantity of air in the tube is small. The resistance of the lamp being variable it is necessary to use a series-resistance auxiliary. This consists of iron wires in a hydrogen atmosphere represented by *h* in the illustration.

Since mercury vapor lamps are very sensitive to voltage variations, conditions may occur in a circuit to which quartz lamps are connected that may cause a current drop large enough to extinguish the lamp. While this would be taken care of by the tilting mechanism, the temporary extinction of the lamp would, however, be annoying. The duty of the induction coil *l* is also to produce, in case of a certain drop of current, a rush of current in the same direction, so that the lamp continues lighted.

The commercial quartz tube lamp for 100 to 130 volts consumes 4 amperes at 85 volts, giving 1,200 "hefner" candles. For voltages between 200 and 250, two lamps are made, one for 2.5 amperes and 160 volts at the quartz tube,

giving 1,500 "hefner" candles, and the other for 3.5 amperes and 280 volts, producing an illumination of 3,000 hefner candles.

Aside from its illuminating features and high efficiency, the quartz lamp possesses insect-destroying qualities, due, supposedly, to the high percentage of ultra-violet rays in its spectrum. The rays of the lamp are said to destroy all flies, moths, mosquitoes, etc., coming within its range.

The Uviol Lamp.—Within the past ten years medical science has made a close study and application of ultra-violet rays in the treatment of malignant skin and circulatory diseases, such as lupus and cancer, and with highly beneficial results. The electro-therapeutic and chemical uses of ultra-violet rays has led to much experimental work, having for its purpose the production of a kind of glass which will not absorb the rich ultra-violet rays in the spectrum of the mercury vapor light. An Austrian scientist, Dr. Zschimmer, has perfected a kind of quartz glass termed uviol, which is very efficient in transforming electrical energy into radiation of very short length. Exposure of the affected parts of the body to the ultra-violet rays for a certain period of time will effect a total cure or give great relief to the patient.

Other uses of ultra-violet rays are in photometric measurements and to cause the union of hydrogen and chlorine. An important use also is in the testing of dyes, as it is the ultra-violet component of the sun's rays that causes its bleaching action. Tests have shown that the light emission from a Cooper-Hewitt lamp fitted with a uviol tube will determine the quality of dyes in a few days. The older method of testing dyes was to expose them to the sun's rays in tropical countries for several months.

The Moore Tube Light is the invention of Mr. D. McFarlan Moore, and is similar in some respects to the mercury vapor light in that it consists of a light source of large area in the form of tubes of hollow glass, varying from 40 to

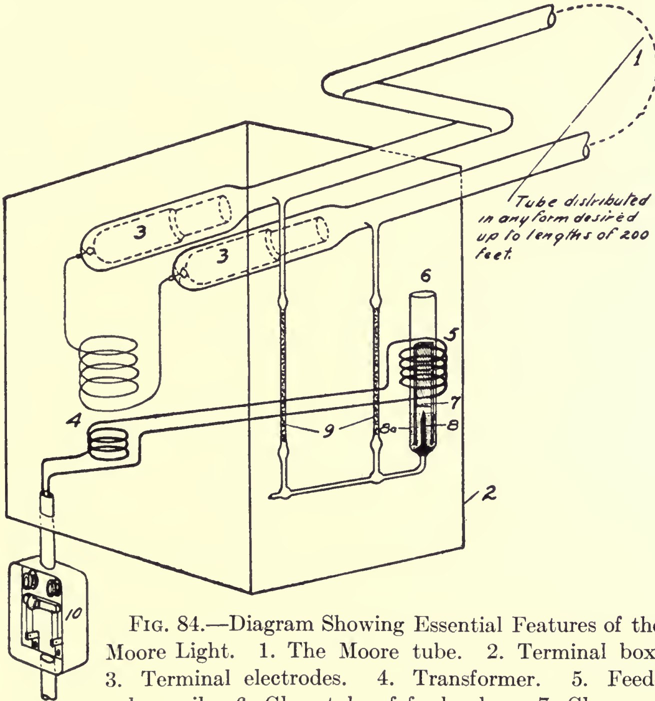


FIG. 84.—Diagram Showing Essential Features of the Moore Light. 1. The Moore tube. 2. Terminal box. 3. Terminal electrodes. 4. Transformer. 5. Feed-valve coil. 6. Glass tube of feed-valve. 7. Glass and iron wire displacer. 8. Porous plug. 8*a*. Mercury. 9. Sand resistance tubes. 10. 220-volt 60-cycle a. c. supply.

over 200 feet in length, the tubes being exhausted of air and filled with a conducting vapor. When the conducting vapor is electrified it becomes incandescent and emits a soft, agreeable light which is very suitable for lighting large interiors and entrances to buildings, and for some

kinds of illumination where a light of low intrinsic brilliancy is desired.

The conducting gas is supplied to the tube through an arrangement which will be presently discussed. The conducting medium may be either nitrogen which emits a yellow light and gives the highest efficiency, carbon dioxide which emits a white light nearly analogous to daylight, or plain air which makes the light of a pale pink tint.

The terminals of a Moore tube, which may be of any desired shape, are led to a piece of apparatus called a *terminal box,* and then are sealed to carbon electrodes which possess the function of conducting the electricity to the gas. A diagrammatic view of the terminal box is shown in Fig. 84. The apparatus consists of a "step-up" transformer (which is an apparatus for increasing the pressure of the supply current) with its high-voltage ends connected to the tube, and a regulating appliance to control the density of gas in the tube. The transformer is supplied with alternating current from any street or power service circuit, but in order to insure a steady, uniform light, a set of adjustable "inductances" must be used in the primary circuit.

A very necessary part of the mechanism is a *feeder-valve* by means of which the gaseous conductor is replenished. The flow of electricity through a conducting vapor will soon cause the vacuum to increase, and in time the light is extinguished. The function, then, of the feeder-valve is to admit air or other gas to the tube only when it is required, its operation being entirely automatic. A sectional drawing of the feeder-valve is shown in Fig. 85. It consists of a piece of glass tubing supported vertically and having its bottom end contracted and extending to

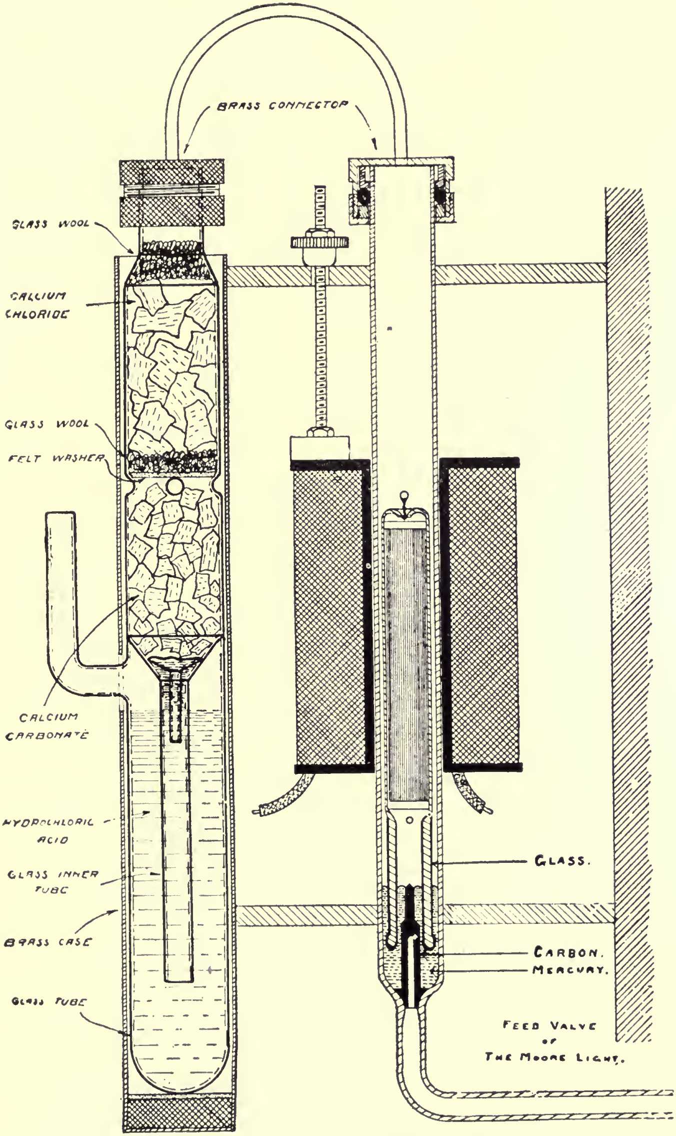


FIG. 85.—Feeder-valve, Moore Light.

the main lighting tube. A small carbon plug is sealed by means of a special cement at the point of contraction of the larger glass tube. The porosity of the carbon plug is insufficient to allow mercury to pass through it, but it will permit gases to pass freely, on account of the high vacuum of the lighting tube connected to the lower end of the plug, and the nearly atmospheric pressure above it. Normally the carbon plug is covered with about a thimbleful of mercury, which serves merely to seal the pores of the carbon plug. Partly immersed in the mercury and concentric with the carbon plug is another smaller and movable glass tube, the upper end of which contains a coil of soft iron wire, which serves as the core of a small solenoid connected in series with the transformer. The duty of the solenoid is to raise the concentric glass tube partly out of the mercury, the surface of which falls and thereby causes the small tip of the conical-shaped carbon plug to be slightly exposed for a second or so; thus a minute quantity of air, or the gas to be used, finds its way into the tube proper. Instantly the air is admitted the vacuum is lowered, the current through it decreases, as does also the current from the mains; hence the feeder magnet weakens, the displacer drops, and the air or gas inlet is closed. This operation is repeated about once per minute throughout the life of a Moore tube.

The degree of vacuum required in the Moore tube lamps is about 0.10 of a millimetre which is comparatively high. This vacuum is maintained within 0.01 of a millimetre or 0.00001 of an atmosphere either above or below the normal degree of vacuum. The constancy of the vacuum is due to the fact that but slight changes in the vacuum result in enormous changes in the electrical resistance of the gaseous conductor. For instance, a tube 220 feet

long at its lowest vacuum (0.11 mm.) takes 24 amperes, but at the end of every minute this has increased to 25 amperes when a new supply of gas causes the current to drop to 24 amperes again. The use of electricity to gov-

Fig. 86.—Moore Light Installed.

ern the vacuum is equivalent to using a multiplier of about 400,000.

The long tube Moore lights (Fig. 86) are constructed in place (usually in rectangular shape) by hermetically sealing together 8 ft. 6 in. lengths of glass tubing, with walls $\frac{1}{16}$-in. thick, by means of a new blast illuminating-gas fire or double-flamed torch. This construction can be rapidly and cheaply done, since in a 100-foot tube about a dozen joints are needed and only about two minutes are required for each one.

The Moore light is also made in portable or unit forms, of which Fig. 87 is an example.

The vapor light possesses a number of advantageous features, chief of which are daylight color value and its low energy consumption for a given illuminating effect. Tests have shown the Moore lamp to have but one-fifth the energy consumption of incandescent (carbon) in 140-ft.

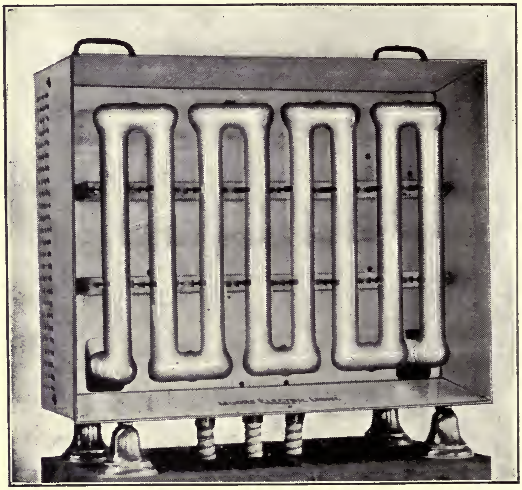


FIG. 87.—Moore Light "Window."

lengths. Operating with carbon-dioxide gas and a white light, a 211-foot tube light had an efficiency 1.5 times that of the arc lamps of the enclosed alternating-current type. The specific energy consumption of the light is given at 2.84 watts per candle-power for tubes 40 feet long, and 1.59 watts per candle-power for 220-foot tubes, operating on nitrogen gas. The energy consumption varies but little with variations in voltage. The light intensity is in direct ratio to the current and the voltage at

which the tube is supplied; this intensity may be made to range between zero and 25 candle-power per foot. The average candle-power is about 10.5 per foot of length. Under good conditions the life of the tube may be over 10,000 hours.

The Moore light is the nearest approach yet invented, to the much-desired cold light, as exemplified in nature

Fig. 88.—Assembly Hall Lighted by Moore Lamp.

by the firefly, and, in the matter of diffusiveness, color, steadiness, efficiency, and safety is on a parity with a number of other electrical illuminants; and it is unaffected by heat, cold, or moisture. The lamp is of low intrinsic brilliancy, emitting a soft mellow light with no bright spots to blind the eye, hence is very suitable for illuminating auditoriums, theatre and hotel lobbies, stores, etc.

Despite the above-mentioned advantages the Moore light possesses several serious disadvantages which make

against its utilization on an extensive commercial scale. Chief of these objections are its indivisibility, imperfect diffusion, fragility, and inefficiency as compared with the tungsten or flaming arc lamps. Its color value is also not that of the continuous spectrum of natural light, but is the

FIG. 89.—Theatre Lobby Illumined by Moore Light.

banded spectrum of gases. Its greatest disadvantage is that of not being a divisible light; a switch is thrown and all the light is turned on; with the Moore light we cannot have a little light here or there as we need it. The indivisibility of the light makes it necessary, in the character of lighting for which it is suited, to supplement it by some other system of lighting which has the feature of divisi-

bility. Again, the fragility of glass makes it impracticable to trust the lighting of an interior of much importance entirely to a long rectangle of glass tubing. Moreover, the breakage of the tube, especially in places hundreds or thousands of miles distant from the factory in which the light is made, and which possesses the only workmen capable of doing delicate glass plumbing, would put the artificial lighting of a building, if done entirely with Moore tubes, out of service for days or weeks.

At the present time the Moore light is also an exclusively alternating-current lamp, and when it is used on alternating current of a commercial frequency, it produces a marked flickering on objects moved quickly in the light. Its power factor is also, in general, low. In places where the objects must be handled with rapidity this is a serious practical disadvantage of the light. Another serious detriment of the lamp as a result of its indivisibility is its unsuitability to localized lighting. Where localized or concentrated lighting is desired, rather than distributed lighting, the economical lighting of certain portions of the room, instead of the uniform illumination of the entire room—a divisible illuminant must be used.

The history of the Moore light is, however, young, and the indefatigable efforts of the inventor in overcoming its shortcomings augurs well for its future as one of the foremost electrical illuminants.

The field of lighting service, for which the Moore light is suitable, is the illumination of art galleries, large interiors, store show windows, advertising signs, etc. Fig. 88 shows the assembly hall, No. 2, of the Engineers' Building, New York, illuminated by a Moore tube light. Fig. 89 shows the lobby of a theatre illuminated by the tube light.

CHAPTER VI

FUNDAMENTAL PRINCIPLES INVOLVED IN EFFICIENT AND ECONOMICAL INTERIOR ELECTRICAL ILLUMINATION

The Relation of Illumination to Physics and Physiology. —One of the paradoxes of artificial illumination is that of two lighting results which, according to physical measurements, are identical, one may be satisfactory and the other unsatisfactory, due to the difference in physiological effects.

An important factor in illumination which produces a direct influence on the physiological effects is the brilliancy of the source of light. When the eye is exposed to light of high brilliancy, the pupil contracts and, although the illumination upon certain objects may be large, as measured by a photometer, the contraction of the pupil causes the eye to gauge the illumination as too low. This phenomenon permits a lower flux density to be employed when indirect lighting is utilized than when bare lamps are exposed to view.

In the laying out of lighting equipments an unavoidable physiological fact which must receive due weight is the demand by the eye for a change in illumination in order to render objects clearly visible and to give the eye a rest. The "fatigue" of the eye is one of its most useful functions to provide self-protection. The wide adaptability of the eye permits it to view objects with a certain degree of satisfaction when the illumination is as low in intensity as the light from the moon or as high as that of bright

sunlight. It is frequently very desirable for the illumination to be non-uniform so that the eye may be rested. For example, in library illumination it is most desirable for the general illumination to be low and to use a high flux density at the reading tables.

The effects of shadows upon the eye are quite deceiving —particularly when shadows are too sharp or not sharp enough. The former is seen in the case of directed light coming from a point source; while in properly diffused light the shadows are eliminated. The most comfortable effect is caused by such a lighting arrangement as will result in an effect between the extremes mentioned. This result is best obtained by the light from a single source of large area, as, for instance, a tubular type of vapor lamp or from an incandescent lamp with an opalescent globe.

In a terse, sententious editorial under the title of "Illumination as a Practical Art," *The Electrical World* of April 7, 1906, thus graphically depicts the defections of much of the present-day illumination. "Considering that artificial illumination must, in a certain sense, have been coeval with civilization, and that, therefore, the art of illuminating has been practised since prehistoric times, it is wonderful how slow has been its progress from an economical or technological standpoint. It is only occasionally that we find ourselves in a hall, building, or enclosure where the lighting at night is at once sufficient, agreeable, and economical. Oftentimes we find an abundance of illumination, but with so much glare in the eyes that they are pained. Often again the light may be pleasant, but the illumination is insufficient for the practical purposes to which the building is devoted. Finally, we frequently meet cases where the light was installed economically from the standpoint of maintenance, but the

contrasts and shadows are distressing. The art of modern illumination consists in giving adequate illumination everywhere in a graceful, uniform, convenient, and pleasing manner, with the minimum waste of light, and the minimum waste of installation, maintenance, and depreciation. One of the most distressing defects frequently observed in lighting is that the luminous source is dazzlingly exposed to the eye instead of being concealed from direct vision. 'Let your light so shine before men that they may see your good works,' and not your naked incandescents or arcs, should be the rule of the illuminating engineer. The sun sets us a shining example in this matter. At noontide in the fulness of his power of about 1,027 standard British candles, he occupies a position outside the ordinary range of view, so that we see everywhere objects sunlit with a mean illumination of about 7,000 candle-feet. When, on the contrary, he sinks at evening into the normal field of view, he interposes hundreds of miles of absorbent air between the tangentially viewing observer and himself, so that the eye is no longer blinded by the glare.

"How different is this practice from that of those designers of a theatre who hang, almost in the line between the stage and its observer, a large cluster of vivid incandescent lamp filaments, having brightness of maybe 40 candles per square centimeter of surface. The retina of the eye is unable to withstand this glare, so the iris diaphragm or pupil of the eye automatically contracts. The observer then sits for several hours trying with pin-point pupils to watch closely the picture presented on the stage beyond, and goes home wondering why he feels so fatigued. Occasionally we see an attempt made to ameliorate this condition by the employment of frosted

incandescent lamp globes, or of frosted outer containing globes. Although these present an enlarged aspect, they are more tolerable to the retina, because the brightness of the light may be cut down to a maximum of only a few candles per square centimetre of emitting surface. But the frosting absorbs an appreciable portion of the total light emitted, so that the benefit to the optic nerves of the observer is not gained without waste. Only at rare intervals do we enter a hall where the light is not only diffused and spread uniformly, but the lamps themselves are concealed from direct vision. When this is skilfully done we not only rejoice in the effect produced, but we unconsciously give salutation to the appreciative care and technically trained forethought of the illuminating engineer.

"The same physiological law pervades the whole domain of domestic lighting. We want to secure a clear picture on the retina of each object we look at in turn, be it a book or a wall portrait. In order to secure this picture on the retina with a reasonable minimum of artificial light production, we need the pupil to be kept widely opened, or the iris diaphragm left large in aperture. If this condition is to be brought about we must cut off all bright light or luminous sources from direct admission to the light camera of the eye. This means that the incandescent lamps must be so placed, or shaded, or englobed that they will not irritate the retina. One of the principal advantages of the incandescent lamp over the gas lamp is that it permits of being so treated to a very marked degree. In fact, it is impossible to secure from gas lighting in general, the same pleasing, decorative, and shaded effect that electric incandescents can be made to furnish with a little care and attention to detail. It pays the central station man-

ager, therefore, to study the rules of physiological lighting, or hygenic lighting, because once the public has been cultivated to appreciate the æsthetic and healthful capabilities of electric lighting, it will not hesitate to adopt incandescent lighting in preference to lighting by flames."

Some Points to be Observed in Artificial Illumination.—The artificial illumination of the majority of rooms is accomplished by a combination of direct and indirect lighting; that is, some light comes directly from the lamps and from the reflector over the lamps, and some is received from the walls by irregular or diffused reflection. If all of our light comes directly from the lamps and reflectors and none from the ceilings and walls by reflection, there will be many sources of light in a room, if sharp, annoying shadows are to be avoided. But in the case of a room with perfectly white walls, the amount of light received from the walls and ceilings by reflection is so large a percentage of the total, that shadows are not so disagreeable. The first step in planning the illumination of any room is a careful consideration of this problem of shadows.

The second important step is the placing of the lamps with reference to the eye. A fundamental fact in artificial lighting of interiors is that the less exposed the lamps are to the direct view of persons in the room, the lower the actual illumination required, because the exposed lamps exercise a well-known blinding effect which causes surrounding objects to appear less distinctly visible than if the lamps were shaded. The prodigious importance of these fundamental facts physiologically must, however, be often ignored when we consider illuminating efficiency aside from the effect on the eye and the overcoming of too sharp shadows.

The word efficiency is applied so loosely in the technique

of illuminating engineering that it is difficult to define it exactly, since so many elements enter into it. Thus the total amount of light emitted by the lamps in a room may be measured and the efficiency of illumination determined from this basis, or the total amount of light received on a plane 30 inches from the floor over the entire room may be measured and the percentage of the total light received on the plane may be called *efficiency of illumination.* Neither of these measures of illuminating efficiency, however, makes allowance for the fact that the illumination may be received in such a way that it is very unsatisfactory to the occupants. For instance, a room may be very efficiently illuminated from a purely technical view-point by suspending lamps at frequent intervals on drop cords and enclosing the lamps in an efficient type of cone-shaped reflector (mirrored), which would cause all of the light to be thrown down on to the level of chairs and tables. Such a method of illumination would, however, be crude and unsatisfactory, since a room so illuminated would be very fatiguing to the eyes, and from an æsthetic view-point would be barbarous, for the reason that the contrast would be too great, the upper part of the room being in semi-darkness, while the lower part would be brilliantly lighted.

The proper and efficient lighting of interiors from both the technical and physiological view-points requires a certain satisfactory proportion between the light thrown upward and that cast downward. Practical illuminating engineers are agreed that in the majority of rooms both large and small, comfortable and efficient results are obtained when from 25 to 35 per cent of the total light produced is directed toward the ceiling and walls, the remaining 65–75 per cent to be directed downward for the direct use of the occupants. This is a general rule subject to

modification in cases where for special reasons more illumination is required on ceilings and walls. But this relative ratio is sufficient to define decorative effects on walls and ceilings properly, while also maintaining the illumination on walls and ceilings at a low enough value so that the lower part of the room will appear comfortably lighted to the persons reading or working therein.

In most instances where a room is poorly lighted, it is due to the fact that more than 65–75 per cent of the total light is thrown on the walls and ceilings. It is an indisputable fact that so many people have been led to believe by charlatans and ignorant inside wiremen that walls and ceilings must be highly illuminated to produce a good lighting effect that they continue to have their residences lighted so that a larger proportion of light is cast on walls, etc., than is obtained from daylight illumination. Thus during the day the lower part of a room is almost invariably lighted to a higher intensity than the upper part, which condition is accepted as proper. Immediately artificial light comes on the conditions are reversed—the upper part of the room being illuminated more than the lower part, provided lamps are suspended high and proper provision is not made for directing the light downward.

These essentials lead to the question, How do modern lamps and reflectors conform to these requirements? As a general proposition it may be stated that all incandescent lamps, if hung pendent and equipped with properly designed opal or prismatic reflectors which come down even with the tip of the lamp, approximate these desiderata.

Up to within the past few years much of the illumination of interiors was designed by rule of thumb and hap-hazard methods of tyros styling themselves *illuminating engi-*

neers; any arrangement of lights sanctioned by the owner of the building being considered good enough if the shibboleth of these tyros—"light, more light" was conformed to. Sad to say, much of the crude and barbarous illuminating effects of the past (and unfortunately of the present also) were approved by some of the largest and most progressive electric lighting companies in this country, any improperly designed lighting installation being winked at, provided it brought in what the company considered sufficient revenue. Indeed, it was the boast of one of these large retailers of light that "it had forty illuminating engineers in its employ." The company, however, failed to state the qualifications their retinue of illuminating engineers possessed to deserve this most serious appellation.

Happily the day is passing when illumination is based on empiricism and guesswork. The dawn of a new era in illumination is upon us, introduced by the newer types of high-efficiency lamps, and aided and furthered by the coöperation of the professional illuminating engineer, the progressive architect, and the modern electric lighting corporation. Illuminating engineering is becoming more and more a fine art—an art in which it is everywhere recognized that technical training, experience, and æsthetic sense are required.

The difficulties which beset the latter-day illuminating engineers in the proper practice of their art are many and varied, as is natural in an art so young as modern illuminating engineering, in which in many cases iconoclastic ideas must combat deep-rooted prejudice and long-continued customs. Under the title of "Trials of the Illuminating Engineer," *The Electrical World* of March 28, 1908, thus sententiously depicts the situation:

"Much has been accomplished in the past three years

in the way of stirring up interest in the proper design of electric-lighting installations, so as to produce good illuminating results, from both a commercial and artistic standpoint. If the experiences of those engaged in planning and trying to have carried out work of this kind could be collected together in book form, it should have a large sale among engineers as a book of humor. At the present time, unless the man who designs the illumination watches the job at every stage of the game, it is likely to be unrecognizable as an engineering attempt by the time it is installed. This is largely due to the slipshod conditions surrounding the work of supplying fixtures and glassware in the past. The job must pass through the hands of so many persons after it leaves the designer, that the chances for mistake or substitution, as well as for wilful tampering with original ideas, are very great. Until there is a more gradual education of fixture makers and hangers, as well as of the owners, it is to be expected there will continue to be the laughable attempts at illumination which we now see on every hand, even though the original adviser may be fully competent. Matters of detail which sometimes appear unimportant make considerable difference in illuminating results as well as appearance.

"Any one who has followed the matter closely can doubtless recall cases where a ludicrous appearance has been produced by the use of wrong shade holders, to say nothing of the illuminating effect being considerably changed from what it should have been, and this in spite of the fact that the most expert advice obtainable had been originally sought.

"In another case a complete floor of a large building, originally planned on the basis of two watts per square foot, was, by a series of oversights combined with consider-

able tamperings with original designs, finally reduced to one watt per square foot, when the actual installation was made, giving results which would have been disastrous had not the tungsten lamp appeared on the market about that time. In another case, through an entire building, shade holders intended for use with Gem lamps, were used only on 16-candle-power lamps, while all the Gem lamps had common standard shade holders. A specification for show-window lighting recently drawn up called for the lamps to be pointed about 10 degrees from the vertical. The wiring foreman modified this so that when the job was finished concentrating reflectors were found pointed at the top of the show-window back, thus giving the greatest intensity where least needed. Changes in arrangement of rooms are frequently made after the original lighting plans are drawn, but seldom is the one who draws the lighting plans consulted about the changes. The results are frequently ludicrous, appearing either in the shape of absurd location of fixtures or arrangements entirely unsuited to the case in hand. There is only one moral to be drawn from these numerous little incidents, which seem to be the rule rather than the exception, where good illuminating work is attempted. If it is a central station company that is attempting to improve illuminating results in its community, it is necessary not only to look after the proper designs, but to have wiremen, foremen, and the whole organization sufficiently educated to the importance of details that designs can be correctly carried out and that substitutions will be largely eliminated. . . ."

Effect of Ceiling and Wall Color on Illumination.—In designing the mural decorations of interiors and in selecting colors for the finish of walls and ceilings, it is most important to choose colors of finish and types of reflectors

which will not exercise a detrimental influence on the efficiency of illumination from both the commercial and artistic standpoints.

One of the most highly practical investigations yet made on the effect of ceiling and wall color on illumination was conducted by Messrs. Lansigh and Rolph, their results being embodied in a paper presented before the Philadelphia section of the Illuminating Society. Their results are of so much value as bearing upon the problem of illumination under different conditions of interior finishes that they are given somewhat in detail.

The tests were conducted in a room 25 feet long by 12 feet wide. It was discovered that to obtain a given illumination on a plane 33 in. above the floor, with ceilings, floor, and walls covered with dark green, and with bare lamps placed at the ceilings (a very unfavorable condition), it required 4.5 times as much electrical energy as to produce the same illumination under the most favorable conditions, with ceilings, walls, and floor very light in color, and lamps equipped with very efficient reflectors. The employment of reflectors in a room in which ceilings, walls, and floor are a dark green (lamps being placed at ceilings as before), reduces the electrical energy required to produce a given illumination about one-half. When all the surroundings are dark the reflectors make the most favorable showing, because a minimum is then received by reflection from the sides of the room. But with light-colored ceilings, walls, and floor, the reduction in electrical energy necessary to effect a certain illumination with reflectors on the lamps averages only 20 per cent. below that needed with bare lamps. The energy to produce a definite illumination when ceilings, walls, and floor are dark is decreased almost as much by changing the ceiling

to light color as by using reflectors, that is, a little less than 50 per cent. The color combinations most generally used are light ceilings with dark walls and floor, or light walls and ceiling with dark floors. Under the conditions referred to, with light ceilings and dark walls and floor, reflectors decrease the electrical energy required about 30 per cent. With ceilings and walls light, the reduction in electrical energy by the use of reflectors was about the same as with ceiling, walls, and floor light, not over 20 per cent. The light cream wrapping paper, with which the sides of the room were covered for the light-color tests, absorbed perhaps less light than any ordinary walls which may be termed light. Likewise, the dark green burlap used did not represent an extreme condition, as rooms finished in dark green and black with beamed ceilings are common.

One of the striking facts brought out by these tests is that, with tungsten lamps in each case, 4.5 times as much electrical energy is required to illuminate a room under certain conditions as under favorable conditions. It is clear that the use of the carbon filament lamp, with one-third less efficiency than the tungsten, would make, on a given illuminating effect, a difference of 13.5 to 1 in the amount of electrical energy expended.

In discussing, under the title "The Economics of Lighting," *The Electrical World* of January 7, 1909, thus effectively presents the situation with respect to haphazard illuminating design: "One must remember that the cost of lighting a room or building is a continuing charge, so long as the room or building is in use. An inefficient installation is a steady item of expense which, if capitalized, may amount to a sum worth serious consideration. For example, suppose some unskilled person has laid out the lighting of a church and has used, by reason of

improper location and shading of the lights, twice as many incandescent lights as were necessary to give the result. If the whole charge thus incurred amounts to \$50 per month, one-half of it, or \$25 per month, represents the cost of the ignorance of the man who did the work. This special example chances to be from an actual case. If one capitalizes this charge, say at 5 per cent, the fact appears that it would have paid to spend several thousand dollars in getting that particular job of lighting thoroughly well planned and executed. The same thing constantly occurs on a smaller scale. Assume, for example, that a man is building a house, and that his architect designs a fine large library to be finished in dark wood and dull green or red paper. It is a demonstrable fact that such a finish, even with a very light ceiling, requires, to produce a given illumination, about three times as much light as if the finish were bright. If four 16-candle-power incandescents would do the work in a light room, twelve will be needed with the dark walls. Assuming half a cent per hour per lamp as the cost of energy, and that the lamps are used three hours per night for 300 nights per year, the continuing charge against the dark finish amounts to \$36 per year. There is no doubt that such finish may be artistically good, but the owner should be brought squarely face to face with the question as to whether it is worth to him an increase of \$3 a month in his running expenses. One often finds rooms, too, in which the finish and the improper location of inadequate fixtures unite to produce a condition in which proper lighting is practically impossible. . . . If well-planned lighting were extremely difficult or expensive, there might be some excuse for this state of things, but on the contrary it is neither. The most fruitful source of failure lies in the fact that lighting is frequently an after-

thought and, by the time it comes under consideration, is considered almost as an extra expense coming upon the top of extras already burdensome. The job of wiring goes to the lowest bidder on the cheapest plans and, while he may do honest work, the result is likely to be bad. If people fully realized the continuing charges against badly planned lighting, they would be willing to go to some expense to gain final economy. Proper lighting can be very readily predetermined, and there is really no excuse for failure unless the character of the fittings is radically changed after the lighting plans have been executed. This should very rarely be necessary if there had been reasonable foresight at the start. In cases where there may be radical alterations of finish after the completion, one should, as it were, take out insurance by putting in a wiring system capable of taking care of the worst conditions likely to be met later, even if part of the outlets are capped and left out of sight. And the same precaution should be taken when a building is subject to considerable change of use. A small amount expended at the start will often obviate heavy alteration charges against the lighting system, as well as the steady waste due to inefficient methods."

Methods of Diffusing Light from High Candle-Power Lamps.—It is admitted by every one that, for eye comfort during continued work, no artificial illuminant can equal daylight when it is received through clean, well-designed windows. Under such conditions daylight is so well diffused that no definite sources of light are recognized, as is the case with artificial illuminants. On the other hand, with artificial illumination we depend upon more or less concentrated sources of light. Two difficulties thus become prominent in high-candle-power lighting. The foremost of these is that in writing upon the highly glazed papers

now common, or in working on lustrous metal surfaces which are fairly good reflectors, there is a considerable amount of regular reflection from the surface under the eye. This glare of regular reflection is so pronounced that when the eye is in some positions, it makes reading impossible, as the glare obscures everything else; in many other positions it is also annoying. This difficulty is the unrecognized source of a great deal of trouble which is experienced in artificial illumination. By properly placing the lamps so that regular reflection does not strike the eye, this trouble can be overcome to some extent, but the solution is not so easy as it sounds.

Practical illuminating engineers are agreed that much of the trouble which is experienced with artificial light could be greatly reduced if larger light-emission surfaces could be employed instead of the intensive light sources of small dimensions now in use. The usual method of increasing the visible light-emitting surface of a lamp is to employ small globes of opal, frosted, or prismatic diffusing glass, or to use frosted lamps entirely. This method, while giving some improvement, leaves much room for betterment, particularly with the higher candle-power lamps now becoming common. The adoption of the inverted bowl-shape of reflector is constantly increasing and possesses the advantages of giving not only a very efficient light distribution at all angles below 70 degrees from the vertical, but also covers the lamp in a way to reduce considerably the intrinsic brilliancy impinging on the eye in case a frosted-tip lamp bulb is employed. This method does not, however, increase the light-giving surface to the desired extent. A more effective plan is to employ very large enclosing globes made of good diffusing glass with a proper reflector located inside the globe. This

increases the initial cost of installation considerably, but gives very much better results by increasing the area and decreasing the light intensity of the surface. A more recent plan, which is justly increasing in popularity, is the use of recesses and false skylights, behind which lamps are concealed, the skylight consisting of diffusing glass. Fig. 95 illustrates this arrangement as applied to the illumination of a show window. The lighting effect produced by properly designed false skylights, so as to give uniform illumination, is most excellent, approaching daylight. Fig. 91 shows a large interior lighted by lamps concealed behind a false skylight.

The solution of the problem of even diffusion from high-candle-power lamps will, however, undoubtedly be found in properly designed indirect lighting. Success with indirect lighting by means of concealed lamps demands the use of reflecting surfaces of proper shape to direct the light down where it is needed, without excessive loss through a number of reflections. The arrangement of the reflecting surfaces must also be such that they can be easily avoided by the vision of the customary occupant of the room. For instance, a large brightly lighted side wall or any other highly illuminated surface in a room causes the iris to close automatically and shut light out of the eye to almost the same extent as a row of bare lamps similarly disposed. The art of indirect and concealed lighting can be developed without prohibitive expense for glassware and fixtures and without undue decrease of efficiency.

Forms of Reflectors used with Incandescent Lamps.—One of the most widely used types of reflectors for the large Gem and tungsten lamps is the bowl form, which has been largely made by the manufacturers of prismatic reflectors, and which has very recently become obtainable in opal

glassware as well. Bowl types of reflectors are especially useful when the light is to be thrown in a downward plane. The especial advantage of the bowl reflector is that it completely covers the filament and greatly protects the eye.

The flat and prismatic reflectors are in considerable use, but are being gradually discarded for general illumination purposes for the reason that they expose too much of the lamp filament to the eye, and also because they permit a large proportion of the light to be projected horizontally, impinging as it does against the walls from which it is reflected back and forth, and a considerable percentage wasted before it reaches the lower part of the room. In general no type of opal or prismatic reflector which will not intercept and reflect the larger percentage of the light emitted horizontally is suitable for the greater part of general lighting.

The two forms of reflectors which are being more and more adopted and with which the most of the scientific illumination of the future will be done, are the deep-bell type which is made at the present time in prismatic, opal, enamelled, and sand-blasted glassware, and the deep-concentrating type.

The particular sphere of usefulness of the bowl reflector is in the illumination of large rooms, each lamp with its reflector delivering about 65 per cent of its light within 75 degrees of a vertical line through the lamp axis. The employment of concentrating reflectors in the same kind of room would result in a smaller area lighted by each lamp, and the illumination at any point will depend more upon the nearest lamps than if bowl reflectors were used; the aggregate effect, however, will not be markedly different with either type.

The obvious field of the concentrating reflector is for all kinds of illumination where light is desired over only a small area. Thus, in the lighting of desks in offices, etc., where lamps are suspended high and the lighting of other objects in the room is not particularly desired, concentrating reflectors are employed. Where large interiors, such as offices and large stores, are to be illuminated, either bowl or concentrating reflectors may be used with equally satisfactory results, if the lamps are distributed at proper intervals apart. The illuminating of long, narrow interiors is, however, a different proposition. For instance, consider a shop of about 20 feet width, with a row of outlets over each counter, the lamps to be necessarily suspended high. The utilization of bowl reflectors near the ceiling would result in an undue amount of light being directed toward the upper walls, which, in the case of dark walls, would be nearly or entirely lost. Hence the use of the bowl reflector, which throws a large flux of light in the region about 45 degrees from the vertical, would illuminate principally the high side wall. Hence, in properly lighting such interiors with a row of lights hung about six feet from each side wall, concentrating reflectors should be used.

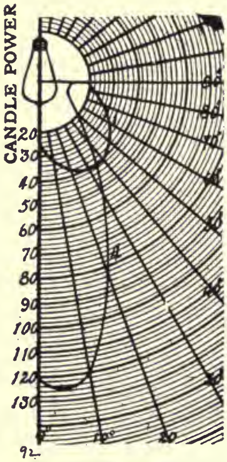


Fig. 90.—Curves of Candle-power Variation with Various Reflector Positions.

It is highly important that the right reflectors be employed with the lamps and their relative position be correct. Untested reflectors and shade holders should not be used in a hap-hazard fashion.

The curves of candle-power distribution (Fig. 90), prepared from tests by Mr. George Loring, show the great variation in candle-power distribution caused by simply changing the position of the reflector to the lamp. Curve 1 (Fig. 90) shows the candle-power distribution of a 40-watt bowl frosted tungsten lamp, fitted with a B-2 crimped Holophane reflector in a given position. By bringing the reflector 1½ inches nearer to the tip of the lamp a distribution shown by curve 4 (Fig. 90) is produced.

A most important fact to be borne in mind in selecting lamp shades is to choose the proper color. Shades and refractors of golden yellow, ambers, and light-browns are safe almost anywhere. In a red room, blue or green shades should never be used, nor should red shades be employed in a green room. Dark-finished rooms are almost impossible to illuminate brightly, and look best when kept comparatively dim. Whether the room be light or dark, the material of the lamp standards and fixtures should never be dark enough to contrast strongly with the lamps.

Illumination of Offices.—The lighting of offices is universally regarded as a very difficult problem in illumination. Most clerical work requires close application and demands such constant service of the eyes that office men are supersensitive to lighting conditions; this is particularly true of large general offices where many employees work in groups. The requirements of the artificial illumination of offices are hence growing more and more exacting, and are receiving more careful consideration daily.

The simplest and most generally employed method of office lighting is the use of small individual units in the shape of either desk or drop lamps. For ordinary conditions, especially where the effective illumination is required only at isolated points, this is a satisfactory method of

illumination; its most flagrant defect being the glare of the lamps themselves, or of the light reflected from desks or papers.

Serious defects in office lighting are the use of multifarious shades on the lighting fixtures and the employment of lamps of very high candle-power, which instead of con-

Fig. 91.—Example of Good Office Illumination.

ducing to better illustration, generally result in increased glare and hence increased eye-strain.

Comfortable office lighting may be obtained by general illumination from moderately large units installed near the ceiling and so arranged as to give uniform illumination. For concentrated working conditions this is a relatively inexpensive method and is cheap to operate. The design of an office-lighting arrangement which will present a handsome appearance and which will also not suggest interference on the part of employees, requires close study of interiors and much care in selecting the proper unit for the lighting effect desired. The light adopted should be

of low intrinsic brilliancy and its diffusing surface large (relatively), so as to avoid glares and objectionable contrasting shadows. The source of light should be one that is economical in operation, and should so distribute the light as to produce an approximately uniform intensity of illumination throughout the room. The candle-power of

Fig. 92.—Natural Illumination of Office Shown in Fig. 91.

the lamps should be as large as practicable consistent with proper distribution of light. For instance, in large offices with high ceilings, a relatively large lamp may be adopted. The lamps and their arrangement for a particular effect are governed by local conditions. In Fig. 91 is shown a splendid example of large office lighting, the natural illumination of the office being shown in Fig. 92, for the sake of comparison. It will be seen that by the use of the ceiling-diffuser arc-lighting system the artificial illuminating effect closely approaches the daylight effect. Fig. 93 is a fine specimen of large office lighting by means of the system described on pages 212–214.

Reflectors for Show-Window Lighting.—The principles governing the design of show-window lighting are in general simple, and the proper results are easy to obtain; but the conditions are too often badly ignored, the idea being to flood the eyes of the passer-by with light of tremendous brilliancy. The blinding, glaring effect thus defeats the

FIG. 93.—A Well-Lighted Office by Indirect System.

purpose of the storekeeper to display wares to the best advantage.

The principal desiderata in well-designed show-window lighting are: (1) That the source of light be concealed from the eyes of the passer-by, or if this be impracticable, so to surround them by diffusing shades that their intrinsic brilliancy will be greatly reduced. (2) That a sufficient quantity of light be thrown upon the goods to be displayed, so that the portion of this light which is reflected to the eyes of the observer will produce the desired effect, *i.e.*,

FIG. 94.—Tungsten-Lighted Show Window.

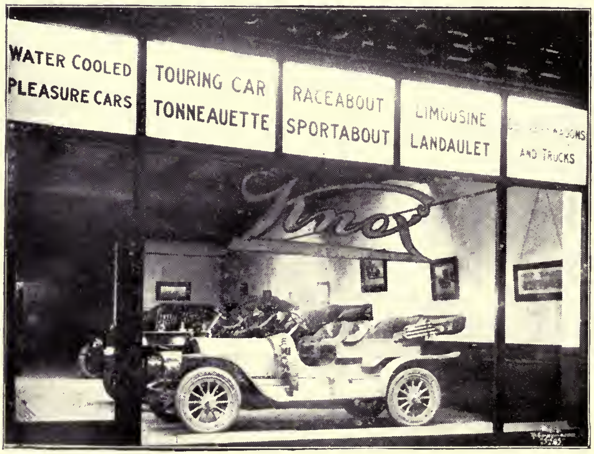


FIG. 95.—Good Example of Concealed Show-Window Lighting.

a strong visual perception of the goods which are on display. There is a considerable number of reflectors made to

Fig. 96.—Nernst Lamp Illuminated Show Windows.

produce these results, some types of which will be illustrated and discussed presently. When tungsten lamps are used for window lighting and are hung vertically pendent near the window ceiling, and equipped with con-

Fig. 97.—A Splendid Example of Show-Window Lighting with Mazda Tungsten Lamps and Frink Reflectors.

centrating reflectors, an efficient and highly satisfactory method of lighting windows is obtained, particularly in

cases where the window has considerable height. Effective show-window lighting necessarily demands not only a frequent change in goods displayed, but the arrangement of the displays. Hence it is very desirable that window-lighting fixtures should be such that the direction of the light can be changed to conform with the periodical changes in window trimming. Figs. 94, 95, 96, and 97 show examples of properly designed window lighting.

Fundamental Principles in Design of Indirect Artificial Lighting Systems.—A very promising field for electric lighting is that of indirect illumination, in which most of the light received in a room for useful purposes comes from the ceiling by diffused reflection from concealed lamps as discussed on pages 213 and 214. The factors which make for satisfactory use of indirect illumination are designs which will not permit most of the useful light to undergo more than one reflection from the ceiling or wall after leaving the lamp and its reflector. Under the best conditions the loss of light from such systems of illumination is large, hence the greater expense of the system over all other interior lighting systems demands also scrupulous cleanliness of the walls and ceilings which act as reflectors. In frequent instances concealed lamps are left unchanged for long intervals and are permitted to become so covered with dirt that their efficiency is much impaired. An every-day observation—that of daylight received through windows by reflection from the sky—proves that the illumination received from large surfaces as in the indirect lighting system is more comfortable to the eye than the light received from points.

A combination of indirect lighting appliances, termed the "I-Comfort System," made by the National *X*-Ray Reflector Company, is shown in Figs. 98, 99, and 100 in-

clusive. The system is intended for ordinary use in offices, residences, and assembly rooms with low ceilings. The general plan of the system is to suspend in a room, at the ordinary height and location of an electrolier, a tungsten lamp with a corrugated silvered mirror-glass reflector underneath. The light is invisible to persons in the room, the light being directed to the ceiling and upper walls and from thence by diffuse reflection to the lower part of the room; this being practicable only where the ceiling is of light color. The reflectors are designed with a shape which produces a large flux of light in the central part of the ceiling near the chandelier. The illumination of the ceiling gradually diminishes until the upper side walls are reached. Much of the light emitted by the lamp is directed toward the central part of the ceiling, from whence it is reflected down to the useful plane with only two reflections and minimizing loss. Fig. 99 illustrates a one-lamp chain fixture for indirect lighting. Fig. 100 shows a two-lamp combination gas and electric fixture with lamps in pendent position. Fig. 101 shows a fixture with lamps upright, which is used wherever it is advisable to install lamps in an upright position. Fig. 102 shows a bedroom illuminated by the "I-Comfort System," using one 48-cp. tungsten lamp, the photograph having been taken by the light of the lamp in the centre of the room.

FIG. 98.—Reflector of "I-Comfort" System of Indirect Illumination.

Fig. 103 is an illustration of the dining-room of the new Blackstone Hotel, Chicago, illuminated by the indirect

system. The lighting is done from large bowls of chiselled alabaster design hung four feet from the ceiling and each containing five 60-watt tungsten lamps and their inverted reflectors.

Notes on the Proper Lighting of Churches.—One of the fundamental requirements in the artificial illumination of churches is the production of shadows in illuminating the face of the person who is addressing an audience, in order that the expression of his face may be clearly seen. Therefore the employment of diffused illumination in front of a speaker's face or illumination from a number of scattered lamps would be bad practice, since neither of them casts shadows, and in such methods of illumination the face is fully illuminated and appears so flat that the expression is lost. For the same reason a strong light from a reflector immediately in front of the speaker, as in theatre lighting (frequently) is ineffective. An engineer of note, Mr. Carl Hering, of Philadelphia, recommends the practice of photographers in making portraits as productive of good church-lighting effects. This practice, as is well known,

FIG. 99.—One-Lamp "I-Comfort" Reflector.

consists in using a certain amount of diffused light coming from a limited direction, together with some small, white reflecting surfaces to accentuate the light from one particular direction above and to one side of the face, so as to produce shadows, but without having any sharp contrasts between lights and shadows. A fault, sometimes seen in the arrangement of concealed lamps, is the placing of an arch of the platform too far behind the speaker to be of any value, or it is placed nearly directly above the speaker's head where the lamps cast shadows. Again, the lamp is placed under the nose of the speaker, sending a glare into his face.

Fig. 100.—Two-Lamp Combination "I-Comfort" Reflector.

The expense is an important factor in the illumination of churches for probably 85 per cent of the lighting equipment. Anything, such as art glass, upon or around the fixtures absorbs the lights and increases the expense. Hence, artistic or sublime effects conduce to the expense of lighting churches; and it is well to avoid much of the decorator's heavy art, such as

stained glass, which decorators are prone to use, as it inhibits effective lighting. The glaring effect of naked lamps is especially objectionable in churches, the softer or subdued brilliance of frosted bulbs or concealed lamps giving the proper effect. The number of lights installed is frequently twice the number that are used. The controlling apparatus of church lights is also sometimes arranged so badly that it is impossible to control the lamps without startling the congregation and distracting its attention.

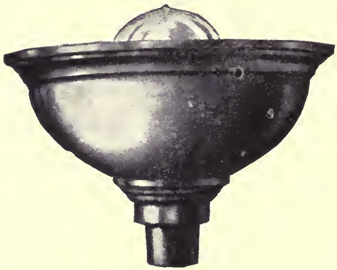


Fig. 101.—Usual Position "I-Comfort" Reflector.

The Lighting of School-Houses.—It is one of the paradoxes of American education that while relatively large sums of money are spent in the construction of pretentious public-school buildings and their subsequent maintenance, there is, nevertheless, a prodigious amount of ignorance or indifference concerning the proper illumination of such edifices—particularly where the buildings are used for night instruction. Commenting on the deplorable shortcomings of much of the illumination done in educational buildings, *The Electrical World* in an editorial in its issue of June 10, 1909, thus depicts the defections of such illumination: ". . . It should be remembered that the public school-houses of our large cities are quite often utilized for evening classes, so that the question of proper lighting rises to an importance that it would not otherwise have. During the ordinary use of the schools by day, artificial light is only required during a part of the year when the days are very short, and on rare occa-

sions at other seasons when the day is greatly darkened by storms, or in unfavorably located school-houses in which the natural light is exceptionally poor. But while artificial light in the day schools is thus commonly needed only for brief periods, it is also true that when such light is needed, it is under the most trying circumstances—that

Fig. 102.—Indirect Lighting of Residence.

is, just at the time when the natural light is failing and needs to be supplemented. This condition means one of two things: either that the artificial and natural light must be used together or that the natural light must be shut out and the artificial light used exclusively. In the latter case the installation for lighting needs to be in every way as extensive as if it were to be used for a large part of the day. In the former case, at least as much light is needed,

on account of the notorious difficulty of getting a satisfactory mixed illumination, partly natural and partly artificial. Just why such a mixture should be so unsatisfactory as it is has never been fully determined. . . . In spite of the importance of good light in the rooms where children are working, it is rather rare to find a schoolhouse properly equipped for artificial lighting. The effect

FIG. 103.—Beautiful and Efficient Indirect Lighting of a Café.

of improper or insufficient lighting in producing progressive *myopia* in the youthful eye is too well known to need comment here, so that the danger of such a defect is obvious. The trouble in the ordinary school-house comes from three causes, sometimes independently present, sometimes acting in evil concert. First, the light may be altogether insufficient in quantity; second, it may be improperly located with reference to the work; and, third, it may be improperly located with reference to the eye

Fig. 104.—Example of Crude Lighting of School-room.

Fig. 105.—Efficient Lighting of Same Room Shown in Fig. 104.

of the victim. Very commonly all three faults coexist. It is not at all unusual to find a school-room with only a single central outlet in the ceiling, for an area of 900 square feet to 1,200 square feet, and this outlet utilized by a chandelier of from four to six 16-candle-power lights. It goes without saying that such an equipment violates

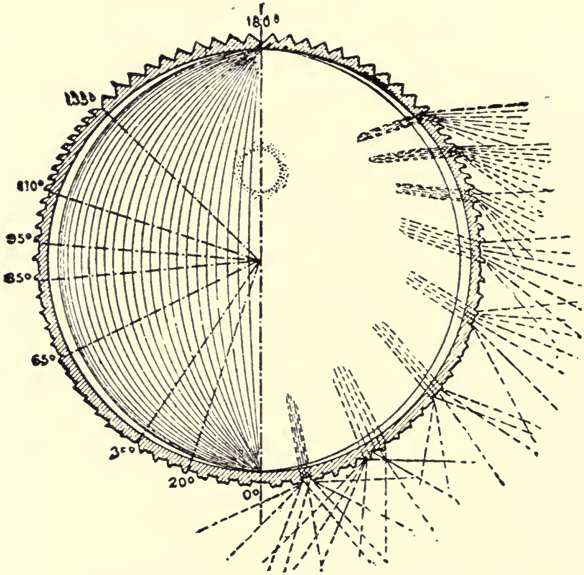


FIG. 106.—Original Holophane Reflector.

every requirement of decent lighting. . . . It is a regrettable fact that the ordinary architect, up to within the past three or four years, has been either absolutely indifferent to, or absolutely ignorant of, the physiological requirements of artificial lighting, and this is nowhere shown with worse effect than within the schools.

. . . . . .

"It is a very easy thing to find a place in an ordinary

school-room where by artificial light one can see from two to six shadows of his pencil point, all fairly well defined and creating optical illusions. Now the remedy for this diffi-

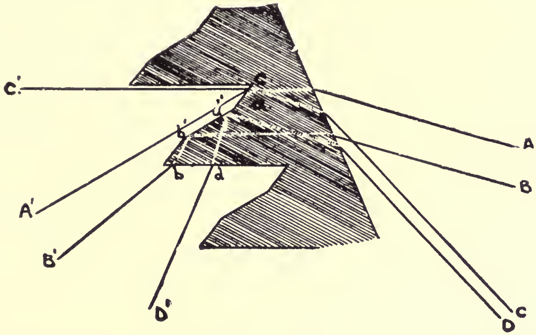


FIG. 107.—Reflection and Refraction Effect of Holophane Reflector.

culty is pretty well known at the present time. It consists in placing the outlets for light unsymmetrically with reference to the rows and columns of desks, so there will be a general tendency all over the room toward reception of

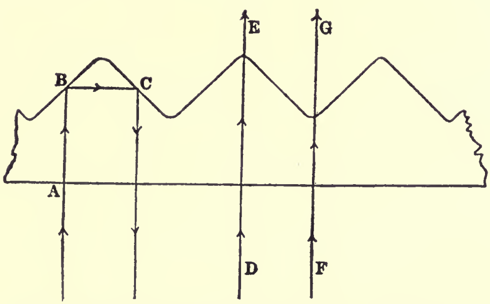


FIG. 108.—Reflection in Prismatic Reflectors.

the light from the left rear direction. This unsymmetrical lighting was independently thrashed out by committees, including oculists, both in London and in Boston, Mass., but

it is very difficult to get a school-house architect—or rather the third acting-assistant draftsman, to whom such trivial matters as lighting are too generally assigned—to depart from the *symmetry he loves to cherish.* Another very common fault is the use of lamps—sometimes even unfrosted lamps, fully exposed to the view, with the customary evil

FIG. 109.—Extensive Type Holophane Reflector.

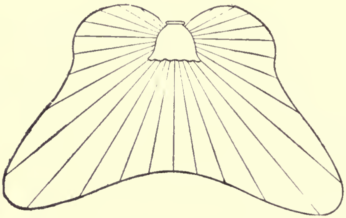


FIG. 110.—Characteristic Curve of Extensive Reflector.

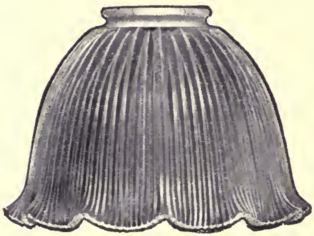


FIG. 111.—Intensive Holophane Reflector.

FIG. 112.—Focussing Type Holophane Reflector.

effects. A beginning of reform has already been made in a few cities, and there can be found, by any one who wishes to study them, very excellent examples of lighting in this and other countries; but on the average it is bad and will continue to be bad until the school committees realize that the eyes of the children committed to their charge are of more importance than the decorative scheme of the schoolroom, or the alleged artistic effect of the lighting fixtures."

Fig. 104 illustrates the crude method of illuminating the ordinary school-room; unshaded lamps being employed, giving rise to glaring effects and poorly distributed light. Fig. 105 shows a school-room efficiently lighted, both from the illuminating and hygienic view-points, about half the amount of energy being used as in Fig. 104.

The Holophane Reflectors for High-Efficiency Lamps represent the highest, but also the most expensive, attainment in the art of reflector design in the utilization of the principles of refraction and reflection for changing the direction of light. The Holophane reflectors consist of a system of scientifically designed prisms suitable for the particular lighting effect desired. Referring to Fig. 106 it will be seen that as originally designed it consisted of a set of vertical internal diffusing prisms. The internal prisms serve to break up or diffuse the light rays. In the enlarged section (Fig. 107) a ray of light A impinging at B will be broken up into two or more diverging rays, so that the eye following back each ray will no longer be able to see the light source and the light is said to be diffused. The external horizontal prisms have both refracting and reflecting faces or are compound as shown in Fig. 106. Thus, rays of light coming from the right direction and impinging on the surface $c'a'$ are merely refracted, or turned from their original course.

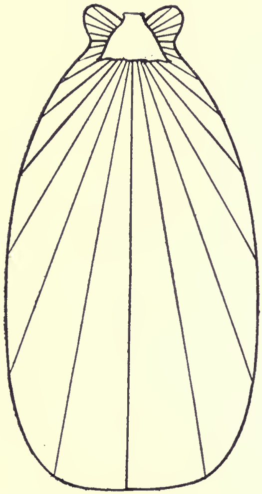


Fig. 113.—Light Distribution of Intensive Reflector.

The Holophane high-efficiency reflectors are designed upon the "merging-prism" principle, and are different in form and construction from the Holophane globes discussed above. In general the interior surface of these prismatic reflectors is perfectly smooth, while the outer surface consists of right-angled prisms designed totally to reflect the light. The principles governing the design of Holophane prismatic reflectors are illustrated in Fig. 108. It will be seen that a ray *A B* is doubly reflected from the right-angled prisms, while rays *D E* and *F G*, which strike at right angles to the surface, pass directly through the glass, so that a reflector does not appear totally dark, but allows enough light to pass through so as not to cast dark shadows on the ceiling. Aside from this highly desirable quality it is feasible by properly shaping the reflector and prisms, to redirect the rays of light in any directions desired.

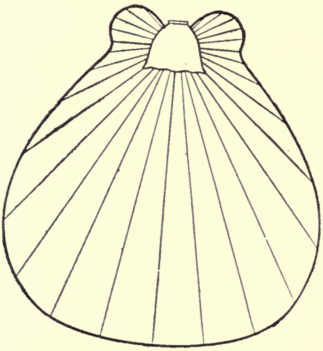


Fig. 114.—Light Distribution of Focussing Reflector.

The high-efficiency reflectors are made in three types, termed Extensive, Intensive, and Focussing. They are all made in the form of "crimped bowls," but give widely different light distributions. The extensive-type reflector was principally designed for use on single lamps to light small rooms or on chandelier lamps in which the reflectors are in a pendent position. The makers also claim it to be suitable for the composite requirements of the following classes of rooms:

1.—Rooms in residences where a single light or group of lights centrally located is employed (the distribution of several units hung vertically being approximately the same as that of a single unit).

2.—Small offices, waiting-rooms, alcoves, etc., where the conditions are substantially as above.

3.—Narrow stores, where a single line of lights is placed down the centre of the room, and where even illumination is desired upon counters located at the sides or down the

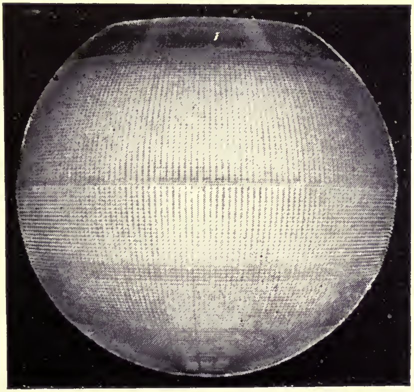


Fig. 115.—Holophane Sphere.

centre of the space, with adequate illumination upon shelves and bins placed against the walls.

4.—Wide hallways having moderate height of ceiling, stock-rooms, workrooms in which high partitions divide the space into aisles, or other cases where even general illumination is desired from a single line of outlets. Fig. 109 shows the Holophane extensive reflector. Fig. 110 shows the characteristic approximate photometric curve of this type of reflector.

The intensive form of reflector is intended for the even

illumination of large rooms by means of distributed units placed in the form of squares. Such methods of illumination are generally used in department stores, warehouses, dining-halls and restaurants, hotel and club lobbies, large offices, assembly rooms, lodge rooms, etc., and in all cases of interior lighting where the lights are suspended well above the plane of illumination. Fig. 111 shows the intensive type of reflector. The curves of this type of reflector are illustrated in Fig. 113. The focussing reflector of service of this reflector includes the illumination of display windows, desks, and counters by rows of lights, and rooms with very high ceilings. The photometric curves of the reflector are shown in Fig. 114.

Fig. 116. — Holophane Sphere.

The Holophane spheres and hemispheres, shown in Figs. 115 and 116, respectively, are used to produce both a decorative and brilliant illuminating effect. Their effectiveness is greatly increased by using a Holophane reflector inside the sphere to increase the downward illumination. Fig. 116 shows the proper mounting of the lamp and reflector within the globes. A type of two-piece Holophane sphere with chain mounting is shown in Fig. 117. A photometric curve of the hemisphere with a supplementary reflector within it as illustrated in Fig. 118 is given in Fig. 120, and shows the

splendid light distribution as well as the increased illumination gained by this equipment.

As the Holophane glassware is designed and constructed

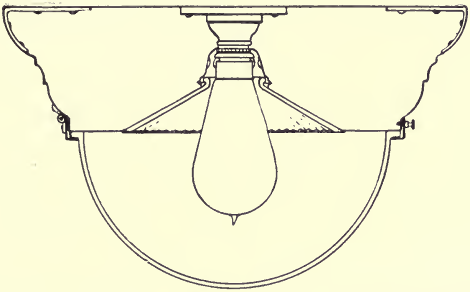


FIG. 117.—Tungsten Lamp Mounted in Hemisphere Reflector.

with scientific accuracy, the use of accurate rules for the proper use of all types of globes and reflectors is quite permissible. The following data pertaining to the use of Holophane spheres and hemispheres were

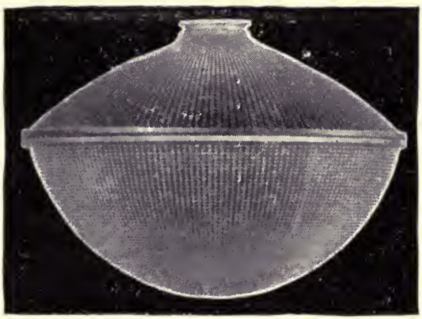


FIG. 118.—Holophane Hemisphere.

worked out by the illuminating engineers of the company and will be found serviceable by the users of such appliances.

DATA FOR THE USE OF HOLOPHANE SPHERES AND HEMISPHERES

To Determine Wattage Necessary

$$\text{Total watts} = \frac{\text{Area} \times \text{foot-candles}}{\text{constant}}$$

The following constants apply for a medium or large room; units 10 to 17 feet above the floor.

Light Unit	Ceiling	Walls	Constant*
Holophane Sphere or Hemisphere with Tungsten lamp.	Light	Light	4.1
	Light	Dark	3.4
	Dark	Dark	2.9

For Gem lamps the constants should be multiplied by .5.

For tantalum lamps the constant should be multiplied by .62.

SPACING RULES

Three Classes of Rooms.

1. Small rooms—one light.
2. Long, narrow rooms—one row of lights.
3. Large rooms—lights in squares.

Class 1. Small rooms—One light in centre. Correct height above plane of illumination = $\frac{1}{2}$ to 1 times the mean length and width.

Note.—The spheres and hemispheres were not designed to give uniform illumination with 1 unit in a room, since this is not desirable in rooms in residences and other small rooms. The larger the ratio of the height to the mean of the length and width, the more nearly uniform will be the illumination.

---

* This constant is known as lumens per watt or the average foot-candles produced by 1 watt per square foot.

CLASS 2. Narrow rooms—one row of lights. Correct height above plane of illumination = $\frac{1}{2}$ to $1\frac{1}{4}$ width of room. Correct distance apart = $1\frac{1}{3}$ × height above plane of illumination.

NOTE.—The spheres and hemispheres are not suitable for large, narrow rooms with one row of lights, when uniform illumination is desired. They should not be used in stores requiring one row of lights, since the illumination will be lower on the counters than in the centre. They are suitable, however, for corridors and hallways. The illumination along the centre of the corridor will be uniform if the distance apart is $1\frac{1}{3}$ × the height above the plane of illumination. If the distance apart is greater than this, the illumination will be lower half-way between lights than directly underneath. This condition is sometimes permissible in corridor lighting.

CLASS 3. Large rooms—light units at the centres of squares or rectangles nearly square. Correct height above plane of illumination = $\frac{3}{4}$ of distance apart.

NOTE.—Uniform illumination is obtained by following this rule.

DATA FOR THE USE OF HOLOPHANE ARCS

TO DETERMINE WATTAGE NECESSARY

$$\text{Total watts} = \frac{\text{Area} \times \text{foot-candles}}{\text{constant}}$$

The following constants apply for a medium or large room; arcs 10 to 20 feet above the floor.

Light Unit	Reflector	Ceiling	Walls	Constant*
Holophane Arc with Tungsten lamps	Clear	Light	Light	4.3
	"	"	Dark	3.3
	"	Dark	Dark	2.6
	Satin finish	Light	Light	3.9
	" "	"	Dark	3.0
	" "	Dark	Dark	2.3

* This constant is known as lumens per watt or the average foot-candles produced by 1 watt per square foot.

For Gem lamps the constant should be divided by 2.

SPACING RULES

Three Classes of Rooms.

1. Small rooms—one light.
2. Long, narrow rooms—one row of lights.
3. Large rooms—lights in squares.

Class 1. Small rooms—one light in centre. Correct height above plane of illumination = $\frac{3}{4}$ the mean of length and width.

Class 2. Narrow rooms—one row of lights. Correct height above plane of illumination = width of room. Correct distance apart = $1\frac{3}{5} \times$ height above plane of illumination.

Class 3. Large rooms—light units at the centres of squares or rectangles nearly square. Correct height above plane of illumination = $\frac{3}{5}$ of distance apart.

Example

Assume a drygoods store on the main street of a small city where stores are well lighted. Light ceiling and dark walls.

Dimensions....	Length	67 feet
	Width	23 feet
	Height	15 feet

$$\text{Watts required} = \frac{\text{Area} \times \text{foot-candles}}{\text{constant}}$$

A good value for the illumination would be 3.5 foot-candles.

In figuring the area, the width may be decreased 2 ft. 6 in. to allow for the shelving. (1 ft. 3 in. on each side.)

Area = 67 ft. $\times$ 20 ft. 6 in. = 1,373 sq. ft.
If clear reflectors are to be used, the constant is 3.3.

$$\text{Watts required} = \frac{1{,}373 \times 3.5}{3.3} = 1{,}456.$$

This store comes under Class 2 (long, narrow rooms). The width, deducting 2 ft. 6 in. for shelving, is 20 ft. 6 in. The height above the plane of illumination, according to the rule for this class of rooms, should be 10 ft. 3 in., or approximately 10 ft. This means 12 ft. 6 in. above the floor. The distance apart should be 1^3 times the height above the plane of illumination, or 16 ft. in this case. The distance from the end unit to the end of the store should be about 1.2 the distance apart. With this store the distance apart may be made 17 ft. and the distance from the end unit to the end of the store 8 ft. For practical purposes this is close enough to the proper values. There will, therefore, be 4 arcs.

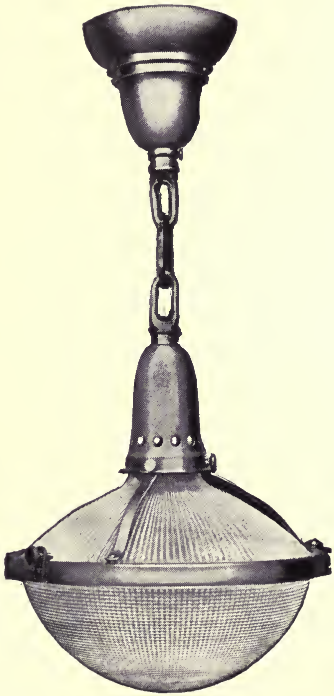


Fig. 119.—Two-piece Holophane Hemisphere.

1,456 watts divided among 4 units makes 364 watts per unit. Arc No. 66 with 60-watt lamps takes 360 watts, a close approximation. The use of four of these arcs is, therefore, the correct solution to the problem.

An ornamental and efficient light-distributing device is the reflector-bowl illustrated in Fig. 121. The lower

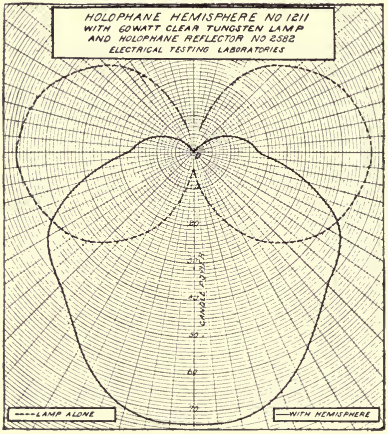


FIG. 120.

half is in the shape of a shallow hemisphere and is constructed with diffusing prisms on both the inside and outside. In this design of reflector a slightly lower absorption

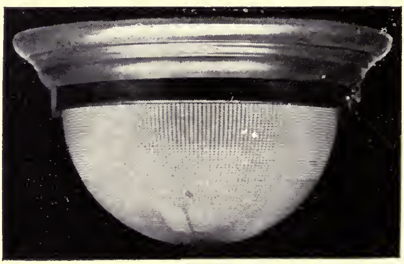


FIG. 121.—Holophane Reflector Bowl.

in glassware is obtained and the use of deep prisms on the exterior of the bowl is avoided, which renders it easier to

clean. The light distribution from the reflector-bowl shown in Fig. 121 is illustrated in the photometric curve (Fig. 122). The data given below have been compiled so as to enable the users of reflector-bowls to utilize them in the proper manner.

DATA FOR THE USE OF HOLOPHANE REFLECTOR BOWLS

To Determine Wattage Necessary

$$\text{Total watts} = \frac{\text{Area} \times \text{foot-candles}}{\text{constant}}$$

The following constants apply for a medium or large room; units 10 to 17 feet above the floor.

Light Unit	Ceiling	Walls	Constant*
Holophane Reflector-bowl with Tungsten lamp	Light	Light	4.9
	Light	Dark	3.9
	Dark	Dark	3.2

For Gem lamps the constants should be multiplied by .5. For tantalum lamps the constants should be multiplied by .62.

SPACING RULES

Three Classes of Rooms.

1. Small rooms—one light.
2. Long, narrow rooms—one row of lights.
3. Large rooms—lights in squares.

Class 1. Small rooms—one light in centre. Correct height above plane of illumination = $\frac{2}{5}$ to $\frac{1}{2}$ the mean of the length and width.

* This constant is known as lumens per watt or the average foot-candles produced by 1 watt per square foot.

Class 2. Narrow rooms—one row of lights. Correct height above plane of illumination = $\frac{3}{5}$ width of room. Correct distance apart = 2 times height above plane of illumination.

Class 3. Large rooms—light units at the centres of squares or rectangles nearly square. Correct height above plane of illumination = $\frac{1}{2}$ of distance apart.

For store lighting and other conditions of artificial illumi-

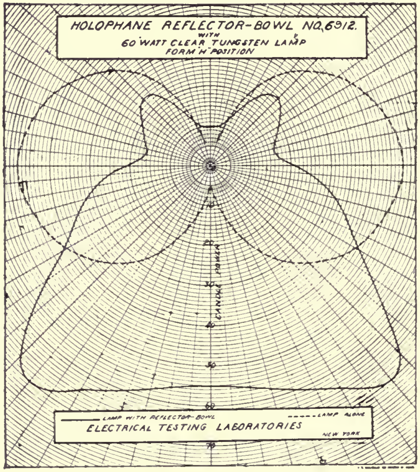


Fig. 122.

nation requiring a wide distribution of light the Holophane arc illustrated in Fig. 123 is well adapted. This type of arc presents a very artistic appearance, is applicable where low ceilings render the use of arc lamps impracticable, and when used on metallic filament lamps brings out color values nicely. These clusters are fitted with distributing reflectors which, while showing up color values in store lighting, also throw the light high on the side walls

as well as give a good illumination in the horizontal plane. The values of light emitted at different angles by a Holophane cluster fitted with high-efficiency lamps is shown in Fig. 124. A steel reflector to which the Holophane principle of construction is applied is shown in Fig. 125.

Data for Guidance in the Use of Holophane Reflectors.—The following tables and rules are reprinted from the bulletin of the Holophane Company; they are considered of special interest to users of prismatic glassware for shades and reflectors of the high-efficiency type.

"*I. The Wattage Required in a Room.*—To find the wattage required to secure the desired illumination, multiply the area in square feet by the intensity in foot-candles desired and divide by a constant in the table below.

NOTE.—The following constants apply where one has a medium or large room with light ceiling, lamps hanging pendent 10 to 17 feet above floor and equipped with Extensive, Intensive, or Focussing Holophane Reflectors.

Lamps	Reflectors	Walls	Constant
Tungsten	Clear Holophane	Light	5.
Tungsten	Clear Holophane	Dark	4.
Tungsten	Enamelled or Satin Finished	Light	4.3
Tungsten	Enamelled or Satin Finished	Dark	3.4
Gem	Clear Holophane	Light	2.2
Gem	Clear Holophane	Dark	1.8
Carbon 3.1 Watt	Clear Holophane	Light	1.8
Carbon 3.1 Watt	Clear Holophane	Dark	1.5

NOTE.—The above constant is known as lumens per watt or the average foot-candle intensity produced by one watt per square foot.

A type of reflector termed "Opalux" has recently appeared, for which all the attributes necessary in an ideal

reflector are claimed—viz., artistic appearance, mechanical stability, ease of cleaning, a minimum liability to become soiled, and minimum limit of cost. The Opalux glass possesses a diffusing surface on the reflecting side. It is a translucent glass, but by means of a secret process of manufacture a diffusing surface is produced entirely different from that obtained by ordinary etching, sand-blasting, or enamelling. Another desirable feature of the Opalux glassware is the removal of the "glaze" of the glass so as to give a high degree of smoothness and thus permit of ready cleaning. The Opalux reflectors emit an illumination of pearly lustre of slightly opalescent tint, with a variation of soft color tints. Several types of Opalux reflectors are shown in Figs. 126 and 127. The *I* reflector of Fig. 126 is designed for 25 and 40-watt metallic filament lamps. The *F*3 reflector shown in Fig. 127 is intended for 100-watt metallic filament lamps. In Fig. 128 a characteristic photometric curve of the Opalux concentrating reflectors is shown, while in Fig. 129 can be seen the photometric curves of the distributing type of reflector.

Fig. 123.—Holophane Arc.

Figs. 130 and 131 show two forms of "Gillinder" reflectors made under Holophane patents. These reflectors produce quite satisfactory results for some conditions of lighting at very moderate cost.

A diffusing cluster, adapted for use with large lighting units of nearly the same candle-power as the enclosed arc, is the General Electric economy diffusing cluster shown in Fig. 132.

The diffuser is designed primarily to carry six tungsten lamps suspended in a vertical position. Very good results,

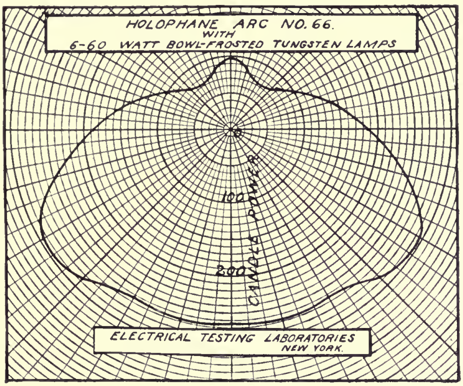


FIG. 124.

however, can be obtained by the use of either tantalum or carbon filament lamps.

The illustration shows the standard 26-inch cluster. The diffuser is made of steel, coated with white porcelain enamel on the under side and black on the top. The supporting reflector is made of brass with a nickel finish, and carries springs to compensate for expansion or variation in the size of the globes. The casing is finished in streaked oxidized copper.

The 39-inch or mill type diffuser is identically the same as the 26-inch, except that the diffuser is larger, and instead of being finished in porcelain enamel is coated with white zinc enamel. For store lighting, the 26-inch

diffuser is recommended, and for mill and factory work the 39-inch gives more satisfactory results as regards distribution and diffusion.

It has been found from experience that the 39-inch tungsten economy diffusing cluster gives excellent results for mill lighting when equipped with three 100-watt tungsten lamps. This permits, for the same energy, somewhat closer spacing than arc lamps.

Fig. 125.—Holophane D'Olier Steel Reflector.

The shade is made of clear glass frosted on the inside, and, as may be seen from the illustration, is curved to take the same general shape of the lamps. Placing the frosting on the inside of the shade gives a lower intrinsic brilliancy than is obtained by the same grade of frosting placed on the lamps, and does not reduce the life of the lamps. The six-lobe shade is standard for all lamp combinations.

Fig. 126.—Opalux Concentrating Reflector.

Care of, Cleaning, and Maintenance of Tungsten Lamps in Prismatic Reflectors.—Since the tungsten lamp is comparatively fragile, and in order to obtain the most satisfactory results with it, particular care must be exercised in handling it.

In large cities where soft coal is allowed and no attempt

made to suppress smoke, incandescent lamps and Holophane reflectors of certain types will fall off from 10 to 35 per cent in efficiency within a period of six weeks, by the accumulation of dust and dirt. The average loss in this time will range from 20 to 25 per cent. Therefore it is a profitable plan for stores, public institutions, and even private residents to establish a regular system of cleaning for both lamps and reflectors, not alone for the

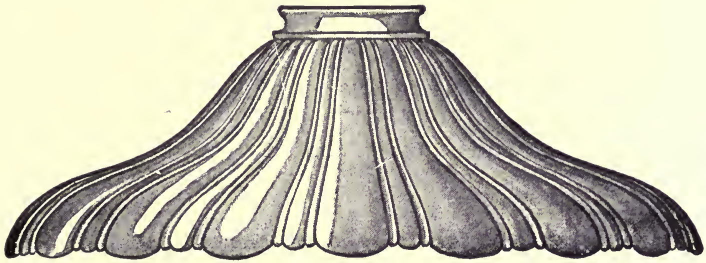


Fig. 127.—Opalux Distributing Reflector.

improved appearance which they present, but to obtain the maximum illuminating results for the money spent in lighting.

Due both to the fragility of the tungsten lamp and its increasing brittleness with age, the following system of cleaning it is recommended: The lamp cleaner for usual routine cleaning should be equipped with a pail of strong soapsuds and water, a small scrubbing brush some four or five inches long with stiff bristles, such as is employed by cooks for cleaning vegetables, and a bunch of rags for washing and wiping. To insure against breakage, the lamps and reflectors should be cleaned while the lamps are lighted, as the filaments are then soft and plastic instead of brittle, as they are when the lamps are cold. The cleaner

should first turn on the lamp to be cleaned. He should wear a pair of dark glasses, as continued exposure of the eyes to high candle-power lights is liable to cause injury.

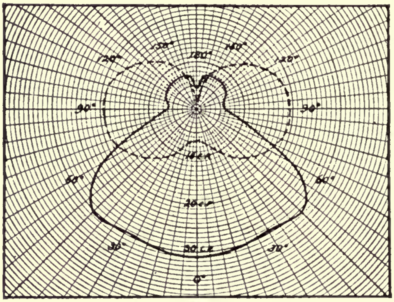


FIG. 128.—Photometric Curves of Reflector Shown in Fig. 126.

The lamp bulb and the inside of the reflector should first be carefully washed with a rag wrung nearly dry, and this should be followed by careful wiping. The outside of the reflector can be cleaned with either a dry or damp brush,

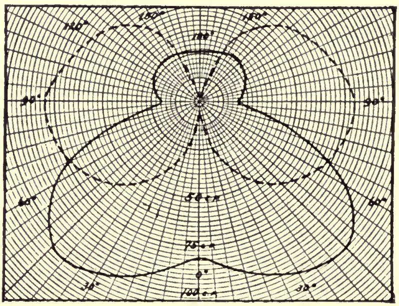


FIG. 129.—Photometric Curves of Reflector Shown in Fig. 127.

brushing lengthwise of the prisms or creases. Ordinary wiping with a cloth is useless for cleaning prismatic reflectors, because the cloth will not reach to the bottom of the

prisms. The wiping of the outside of the reflector dry is not absolutely essential. The cleaning described should be done at least once a month.

Users of a considerable number of tungsten lamps should

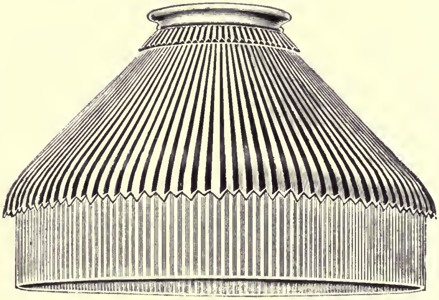


FIG. 130.—A Skirt Type of Prismatic Reflector.

keep a stock of four or five on hand, thoroughly cleaned by scrubbing in a pail of water with soap, with extra lamps also. In replacing a burned-out tungsten lamp, a clean reflector should be placed on the fixture at the same time

FIG. 131.—Distributing Type Prismatic Reflector.

that the lamp is renewed, and the reflector formerly on the lamp removed, well cleaned, and put in the store-room. This system will insure each reflector receiving a thorough cleaning when the lamp is renewed, and the necessity of

running the risk of breakage of lamps by removing the reflectors from the fixtures before the lamp is burned out will be entirely obviated

Practical Fixture Design.—The progress of illuminating engineering has been, and is now, to a large degree slow, being retarded by the *laisser faire* policy of fixture designers

FIG. 132.—Diffusing Cluster for Large Incandescent Lamp Units.

in the matter of keeping abreast of the requirements of modern high-efficiency illuminants. Fixture designers are so conservative as regards improvements in their wares, both from the technical and artistic view-points, that only the most insistent demands of the illuminating engineer, architect, and contractor will result in the betterment of existing conditions. Commenting on the shortcomings of fixture

manufacturers *The Electrical World,* in an editorial of its February 1, 1908, issue, truthfully says: ". . . It is unfortunately true the country over that fixture makers and dealers are taking little or no interest in illuminating engineering. They are rather waiting for customers to demand and drive them into making improvements which will secure better illuminating results. One would think that before this any number of enterprising fixture houses would, in their own interests, have begun to look after effective illumination for the sake of standing well with customers, but such does not appear to be the case. It seems rather to be a case of the fixture dealer blaming the architect and the architect the fixture dealer. In the mean time we must look for most of our improvements in illuminating results to central station men and electrical contractors, who usually have some appreciation of technical points and who, by dint of much insistence, may be able to get the fixture men to supply what they specify, even though the fixture man may, as is often the case, make strenuous efforts to substitute some stock standard of inefficient design. When the day comes that efficient designs become the regular stock articles instead of the special exceptions, as now, efficient illumination will be much more common.

". . . It has sometimes been said that the illuminating engineer has too little regard for the artistic. . . . For example, we frequently hear art glass fixtures condemned by the wholesale as being contrivances of the evil one, with which it is impossible to produce good illuminating results under any conditions. There is no inherent reason why art glass fixtures cannot be built which will give excellent illuminating results for certain conditions, and at the same time resemble so closely those now commonly

seen that the ordinary observer would notice nothing unusual about them. The art glass may in some cases be very useful as a diffusing screen to keep the glare out of the eyes. The box type of fixture is capable of great development along scientific lines, care being taken either to leave the bottom open or to cover it with a diffusing glass which will not absorb much light. The same principle can be applied to art glass lanterns, provided the design of the lantern is such as to let useful light out through the bottom, utilizing the art glass sides simply as shades and diffusers. In ceiling hemispheres we have a very satisfactory means of diffusing and softening light and of obviating the necessity of conflicting with the idea of the architect through the use of obtrusive hanging fixtures. Unfortunately, the ceiling hemisphere has commonly been used in a very inefficient manner in the past, and without any attempt to recover and utilize the 50 per cent of light which goes upward from the incandescent lamp when used without a reflector. The use of efficient reflectors inside of ceiling hemispheres would seem to be the most obvious improvement. . . ."

Preliminary Calculation of Illumination.—It was formerly the practice in figuring the illumination required for rooms and interiors of various kinds to use what is called the point by point method, which consists in measuring the intensity of illumination at different typical points and arranging these values to find a mean average in foot-candles. This is a laborious process and it also has the disadvantage of not giving the true average foot-candles, unless the foot-candles are calculated for a sufficient number of equally spaced points over an area of the room sufficiently large to make the average of these points equivalent to the true average of the room. The point by point

method also does not allow for the added illumination due to reflection from ceilings and walls.

The result of tests made on all kinds of lighting installations during the time high-efficiency lamps have been used have enabled results to be predetermined for a large number of conditions employing the different types of such lamps. The values from these tests have been compiled in the form of a table by Messrs. J. R. Cravath and V. R. Lansigh, prominent illuminating engineers of Chicago, which forms a valuable basis for arriving at the required illumination of different kinds and sizes of interiors. The table appeared in *The Electrical World* of July 11, 1908, and is herewith given by permission of the publishers. The table shows the watts per square foot received to produce an average illumination of one foot-candle on a plane about 30 inches from the floor, in various large rooms with various electric-lighting appliances. The values given are based on average conditions, with lamps and reflectors reasonably clean and lamps varying not more than 10 per cent of their rated candle-power.

TABLE SHOWING NUMBER OF WATTS PER SQUARE FOOT OF FLOOR AREA REQUIRED TO PRODUCE AN AVERAGE OF ONE FOOT-CANDLE OF ILLUMINATION (WATTS PER LUMEN)

INCANDESCENT LAMPS

Tungsten lamps rated at 1.25 watts per horizontal candle-power; clear, prismatic reflectors, either bowl or concentrating; large room; light ceilings; dark walls; lamps pendent; height, 8 to 15 feet	0.25
Same with very light walls	0.20
Tungsten lamps rated at 1.25 watts per horizontal candle-power; prismatic bowl reflectors enamelled; large room; light ceilings; dark walls; lamps pendent; height, 8 to 15 feet	0.29

e with very light walls.......................... 0.23
lamps rated at 2.5 watts per horizontal candle-power; clear, prismatic reflectors, either concentrating or bowl; large room; light ceiling; dark walls; lamps pendent; height, 8 to 15 feet.............. 0.55
Same with very light walls........................ 0.45
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; clear prismatic reflectors, either bowl or concentrating; light ceiling; dark walls; large room; lamps pendent; height, 8 to 15 feet........ 0.65
Same with very light walls........................ 0.55
Bare carbon filament lamps rated at 3.1 watts per horizontal candle-power; no reflectors; large room; very light ceiling and walls; height, to 14 ft. 0.75 to 1.5
Same; small room; medium walls ....1.25 to 2.0
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; opal dome or opal cone reflectors; light ceilings; dark walls; large room; lamps pendent; height, 8 to 15 feet 0.70
Same with light walls 0.60

NERNST LAMPS

110-watt, single-glower Nernst lamp, opaline ball globe; no reflectors; large room; light ceiling; medium walls 0.50

ARC LAMPS

5-ampere, enclosed, direct-current arc on 110-volt circuit; clear inner, opal outer globe; no reflector; large room; height 9 to 14 feet 0.50

The application of the above table is based on the simple rule: Total watts = area of room × foot-candles × constant from table.

The examples herewith given show the application of the table. Required the number of watts to illuminate a room 14 × 16 feet, or 224 square feet of floor area, with light ceilings and dark walls, if the average illumination desired is 3 foot-candles. Referring to the table we will observe that the use of tungsten lamps with prismatic

bowl reflectors will require 0.25 watt per square foot to give one foot-candle. Hence there will be required 224 × 0.25 × 1.3, or 168 watts to illuminate the room. If 25-candle-power tungsten lamps are used, eight will be needed; or one 100-watt and three 20-watt lamps may be used.

As another example, consider a large general office-room 50 feet × 75 feet or total area 3,750 square feet, which is to be illuminated with an average intensity of four foot-candles with Gem lamps. Referring to the table we note that one foot-candle with such lamps requires 0.55 watt per square foot. Multiplying 0.55 by four foot-candles gives 2.2 watts per square foot. To illuminate 3,750 square feet, therefore, twice this or 7,500 watts would be required. This can be done with 60 125-watt lamps, arranged for symmetry in six rows of ten each.

In illuminating interiors of considerable area, it is generally recognized that the use of a large number of light sources is not desirable, and in employing metallic filament lamps in such work, the use of "luxoliers," "lumineers," or other such concentrating light reflectors give the most efficient results from the physiological viewpoint.

Foot-Candles for Various Classes of Interiors.—The following table shows the approximate values of illumination required by various classes of interiors:

Corridors, halls, etc.	0.5 to 1
Depots, assembly halls, etc.	0.75 to 1.5
Churches, business offices, libraries, schools, etc.	2 to 3
Machine shops	2 to 5
Stores	2 to 3.5
Stores (dark goods)	4 to 6
Saloons, Cafés (depending on brilliancy desired)	2 to 5
Engraving shops, draughting rooms, etc.	5 to 10

CHAPTER VII

NOTES ON STREET ILLUMINATION

Fallacies in the Design of Street Lighting Systems.—The key-note in the unsatisfactory illumination of American streets, as compared with the streets in the leading European cities, is a lack of appreciation of what constitutes *real lighting* of streets. When cities undertake to do real lighting on their streets, many of the present-day difficulties in obtaining satisfactory street lighting will disappear. Fig. 133 is an example of good street lighting.

Central stations have been in this defection largely at fault, in that they have viewed street lighting entirely as a commercial proposition and not as an art; and without good advice councils have considered the question only when brought before them as they would one of street paving. The time is ripe for the National Electric Light Association to take the initiative in the matter by presenting alternative plans for lighting various classes of streets, thus enabling municipal officials to compare what the best practice would indicate with what central station men propose.

The most common fallacy is in giving undue importance to small candle-power units. By properly distributing such units it can be demonstrated that a more uniform illumination can be obtained than from large units; and well-designed illumination with small units can be made highly efficient. The danger lies in the simple substitution of small lamps for large ones without insisting on

Fig. 133.—Fine Example of Proper Street Lighting.

equivalent energy or luminous flux. Under average conditions of practice equality of cost is not synonymous in meaning with equality of light. As a concrete case, the substitution of three 60-candle-power incandescent lamps for one arc lamp may be done without change in price and with a higher minimum illumination resulting; but to obtain equal flux of light available on the street would necessitate the use of five or six incandescents instead of three. Dividing the aggregate candle-power into a number of small units results in a higher cost for the equivalent lighting in frequent instances; it also adds to the cost of service. The problem is frequently one of degree, since a street well lighted by arcs at average price can be equally as well lighted by incandescents at the same prices, but an unsatisfactorily lighted street may be considerably bettered with noteworthy economy by a like substitution. In small towns or villages, however, lighted by widely spaced arcs, subdivision of units offers the most advantages.

A fertile cause of misunderstandings and litigations in street illumination is the continued employment of nominal candle-power ratings for arc lamps. "We wish there could be permanent cessation of such foolishness," says *The Electrical World* (editorial, April 20, 1909), "and that street lights could be sold for what they are and not on the basis of ratings known to be erroneous. In the earlier days of arc lighting a 2,000-candle-power arc meant just one thing—an open direct-current arc, taking 9.5 to 10 amperes and 45 to 50 volts at the lamp. It, therefore, created no confusion to have erroneous candle-power ratings, since the buyer knew very early in the game that the rating was a humbug. At the present time, however, one can find in the tabulated data, published from various

sources, direct-current open arcs, as above, direct-current enclosed arcs at anywhere from 5 amperes to 6.6 amperes, alternating enclosed arcs at 6 amperes to 7.5 amperes, and even 300-watt magnetite and 250-watt titanium arcs, all passing off as of 2,000 candle-power. It would take the wisdom of the serpent to assign the real candle-powers to such a collection, but all of them are enormously below the rating, and they vary among themselves by 100 per cent or more, whether one reckons candle-power or effective illumination."

The employment of illumination measurements to determine the values of effective light on a street are instructive, but frequently lead to fallacious reasoning. The values so obtained are factors not only of the *particular illuminants* used, but also of their location, height above the street, kind of reflecting system, if any, and a variety of details connected both with the illuminant and the service to which it is put. The usefulness of measurements of illumination of streets is governed more by the conditions and environments under which the test is made than by the lamp itself. Consider, for instance, the simplest case of lights uniformly spaced over the centre of a narrow street free of trees and other obstructions, so that the measurement of illumination at any point may be obtained with a fair degree of accuracy. In a comparison of two similar streets lighted by different illuminants, these measurements will afford a reasonable basis of the relative effects and the cost of obtaining them. But if measurements of illumination are attempted on streets of considerable width with lamps arranged along the curb, and with a length of streets containing dense tree foliage, the results cannot be properly compared with measurements of another wide street with different grouping of lamps and different kinds

and arrangements of trees. As yet there is no specific agreement as to the proper basis for the lighting of streets when areas and not distances from the lamps are concerned.

With the brilliant illumination of streets which obtains abroad and with lamps spaced close enough to give a fair degree of uniformity, illumination measurements would be much simplified. In lighting practice with lamps distributed 400 to 500 feet apart the results of measurements are farcical, because in a large portion of the range of illumination the lighting is negligibly low, and there is also a reduction to an average of bright lighting near the lamps and darkness between them.

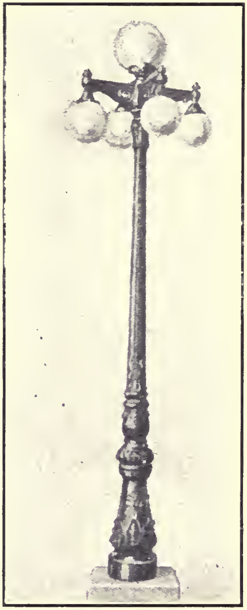


Fig. 134.—A Type of Ornamental Post for Tungsten Street Lighting.

In the illumination of streets by arc lamps placed less than 20 feet from the surface of the street, the present method can be improved by raising the lamps to a height of from 30 to 40 feet. This will result in a considerable decrease of the illumination immediately below the lamps, but the illumination half-way between the lamps will not be appreciably altered. The lamps will also be removed from the field of view with an improvement in the direction of the shadows. Avoidance of the sharp shadows produced by an open arc lamp or by an enclosed lamp fitted with a transparent globe is readily obtained by the use of an

opalescent globe, but the use of this method results in an alteration of the space distribution of the lamp. The best results can be obtained by employing prismatic globes which eliminate shadows and yet diffuse the light uniformly.

Ornamental Curb-Line Illumination—Systems of Various Cities.—In most cities the post form of street lighting is now the most popular, the reasons for which are that the post offers less menace to firemen during a fire, and during the day the dignified, artistic appearance of the post is a most important factor in its adoption.

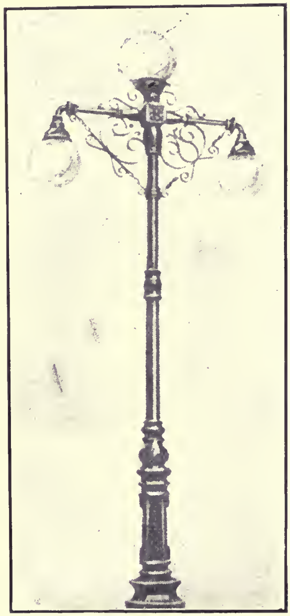


Fig. 135.—An Artistic and Well-designed Lamp Post.

The type of post studded with high-efficiency (tungsten) lamps, which was adopted by the Commercial Club of Des Moines, Ia., for use on the principal business streets of that city, is shown in Fig. 134. The spacing of the poles as prescribed by ordinance is not more than 56 feet nor less than 44 feet. The cost of the pole casting is \$59. The total cost set up complete in place and connected to the lighting mains is \$85. The cost of the poles is paid for by the property owners of the street thus lighted, while the tenants pay for the operation of the lights in front of their places of business. Each pole has a lock-switch in the base, and the lamps are switched on by the patrolman, at the time he turns on the lights

in windows and signs, on a flat rate. The lights are turned off at midnight. The rate per year for each pole equipped with five 100-watt tungsten lamps is $69.50.

Another type of artistic and well-designed lamp post used in Superior, Wis., is shown in Fig. 135. The side lamps on this post are 100-watt tungstens while the top lamp is a 40-watt tungsten. The posts are wired so that the side lamps may be turned off at midnight, the middle lamp being left burning all night. The posts are spaced 55 feet apart on both sides of the street, or 16 on a block. The cost per post is given at $80 complete. Energy is supplied

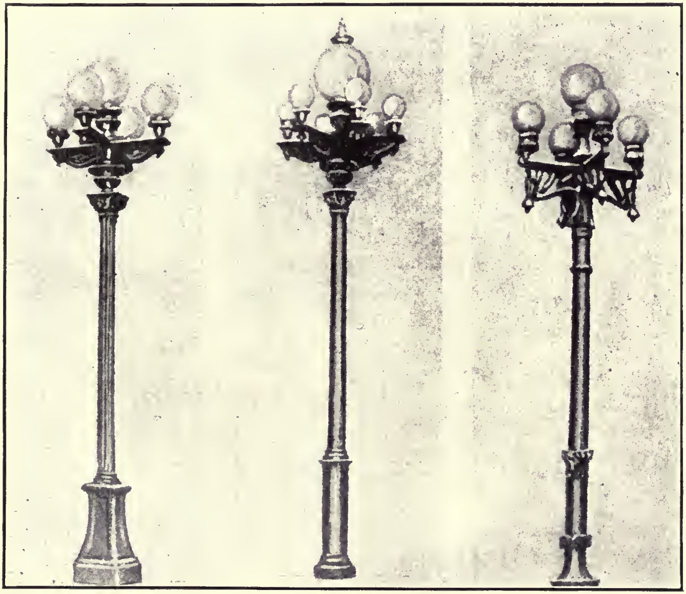
FIG. 136.—Night View of Street Lighted by Post Shown in Fig. 135.

them from an independent circuit set in a groove, which was chipped in the edge of a cement walk. (This system of connecting the poles by setting a conduit in a groove chipped from the edge of the walk is in very general use in street lighting work.) The handsome appearance of a street in Superior (a city of 50,000 population) is shown in the night view, Fig. 136.

In Los Angeles, Cal., several closely similar types of lamp posts are employed on the business streets of the city as shown in Figs. 137 *a*, 137 *b*, 137 *c*. These posts are spaced 115 feet apart on both sides of the street. They are fitted with five globes, each containing three 8-candle-

power lamps. The shadows cast by the central portions of these posts is a serious defect.

Two types of lamp posts, used in lighting Fifteenth and Sixteenth Streets, Denver, Col., respectively, are shown in Figs. 138 and 139. A square ornamental casing (Fig. 139)



a *b* *c*

FIG. 137.—Types of Ornamental Lamp Posts Used in Los Angeles.

is placed over a street railway pole. The posts are spaced 90 feet apart, or four pairs to a block. One of the arc lamps is a dummy which is used only to give a more symmetrical, balanced appearance to the post by day. The casing of the street railway pole cost $160. The cost of lighting is met by the city at an expense of $60 per lamp per year. The ornamental bracket shown in Fig. 139 is

merely attached to the metallic street railway pole at a cost of $50 per pole.

The type of lamp post used on Nicollet Avenue, Minneapolis, is shown in Fig. 140, and is of most pleasing design. The posts are of cast iron and stand 14 feet above the ground, and when the lights are turned on produce a very beautiful effect. On the tops of the posts the four arms support the 12-inch round alabaster globes, one on the end of each arm. Each globe is equipped with one tungsten lamp mounted in an upright position. The upright position of the globes conduces to greater cleanliness, minimum breakage, and greater lighting area. The top of the post itself contains a 16-in. globe similar to the others, which also contains one 100-watt tungsten lamp, making the

FIG. 138.—One Type of Lamp Post Used in Denver, Colorado.

total wattage per post 500. The posts are placed eight to a block, four on each side of the street, so arranged that when the side streets are connected up, a uniform spacing of 100 feet between posts will be maintained.

The initial cost of the posts installed in Minneapolis is $145 per post; of which amount $85 is for foundry work

Fig. 139.—Artistic and Efficient Post Design for Arc Lighting.

and $60 for wiring, globes, and lamps. The maintenance charge, including renewals of lamps, washing of globes, painting of posts, etc., is $78 per post per year.

All of the lamps on the post are switched on at dusk. The four lamps on the arms are turned off at midnight, leaving the pilot lamp on top of the post burning until daylight.

The cost of first installation and of operating is met by assessing merchants $2 a front foot to cover installation, and $1.25 per front foot for maintenance.

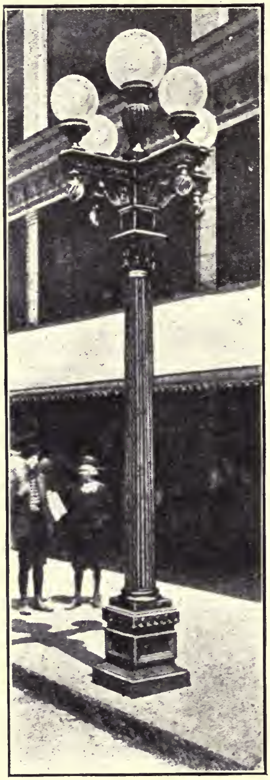


Fig. 140.—Attractive Post for Tungsten Lamps.

Lamp Posts versus Street Arches.—The intense interest, now being shown in the progressive cities of the country for superior lighting effects in the business sections, has resulted in the adoption of two different methods of lamp suspension. The first, of which the lighting of Canal Street, Grand Rapids, Mich., is an example, consists in suspending tungsten series lamps on stringers across the streets, these stringers being in some instances raised to a peak over the centre of the street, and in other cases supported by intermediate wires, or by piping, so as to have the lights form an arch. The other method of display street lighting attempts to produce the same effect by means of closely-contiguous lamp posts, the posts being from 8 to 14 feet high and equipped with from one to five tungsten lamps, the average being a post of 10 feet in height with from two to three lamps per post. In most instances the cost of installation, including lamps and supports, is paid by merchants' associations of the street or block specially

illuminated, but the spacing and arrangement of the lights are generally under the control of the local lighting company. Due to the fact that each of the two methods of lighting exercises a decidedly different effect on the indoor lighting of buildings, careful consideration should be given the merits and demerits of the two methods.

The chief advantages of the arch system are ease of installation of the arches or suspended stringers of lamps and their generally lower initial cost. Their disadvantages are that they involve a type of construction—a mass of overhead wires—which is very objectionable from the artistic view-point and liable to be a source of danger in case of fire. In high winds they are also liable to serious damage. The suspension of lamps on stringers places the lamps at such a height that a considerable portion of the light is wasted on the upper stories of the building, causing at the same time a glare that may be very annoying to persons living in the upper stories of the buildings. This latter objection is usually considered nugatory by the business men, since with high suspended lamps the intensity of illumination of side walls is sufficient for the existing methods of store and window lighting.

The salient advantages of the lamp-post method are that modern and approved types of construction are practicable by employing ornamental lamp posts and underground wiring, the permanency and artistic effect of which are an important item. When properly designed it is more effective in throwing light on the streets and walks and more dignified. The chief disadvantage from the consumers' view is that the use of lamp-post lighting, using the same energy as the stringer system, means a much more intense lighting of both store fronts and walks, so that the lighting of both stores and windows must be increased considerably.

Illumination with Series Tungsten Lamps.—During the past three years the employment of incandescent lamps for suburban and residential street lighting has made considerable progress, and incandescent lighting systems are coming to be considered ideal for the peculiar conditions to be met with in this character of lighting. The advantages of series tungsten lighting are especially prominent in sparsely settled districts; since, in order to obtain a reasonable illumination between lamps, the greater cost of arcs does not warrant their proper spacing. Moderately low-candle-power units, spaced at frequent intervals, will much more economically light a street. The development of the series tungsten lamp in 1908, with an efficiency of 1.25 watts per candle and an average life of 1,500 hours, has already greatly widened the field of service of metallic filament lamps.

The "*Mazda*" type of street series tungsten lamp, consuming 250-watts and equipped with the most modern "wave reflectors," gives about 250 candles in a direction suitable for street lighting and exhibits a remarkable life, the burning period averaging well above 1,300 hours, which figure includes burnouts and breakage. It is claimed that, lamp for lamp, the 250-watt Mazda tungsten may be substituted for the direct-current arc of 300–330 watts and 1,200 nominal candle-power, and for the alternating inclosed arc of 400 watts. In substituting lamp for lamp, the power required is reduced from 330 watts to 250 watts with reference to the direct-current arc, and from 400 watts to 250 watts in case of the alternating-current arc. In the latter case there is a 37 per cent increase in the capacity of the power equipment, including series transformers, generators, and engines.

Fig. 147 illustrates the efficient illumination of a sec-

tion of Central Park, New York, with the series tungsten-lamp system.

These lamps are at present made in 25-, 32-, 40-, 60-, 80- and 250-candle-power sizes and for currents of 3.5, 4.0, 5.5, 6.6, and 7.5 amperes, and also in candle-powers of 25 to 60 for 1.75 amperes. Their greater life as compared with the multiple tungsten lamp is largely due to the greater cross-section of the filament, and also to the fact that vibration caused by linemen climbing poles and driving bolts, windstorms or passing traffic, do not affect the lamp. A very noteworthy advantage of the tungsten over the carbon series lamp is that the tungsten lamp gives equally good results on all amperages, and does not require one circuit for incandescents and another for arc lamps, as has been the case with carbon lamps used for this purpose.

The tungsten series lamp for street lighting possesses a twofold economy: (1) in the kilowatt-hour saving per year, and (2) in the capacity of transformers and station apparatus. As an illustration of the former advantage we will take the case of the 32-candle-power lamp burning 4,000 hours, all night, every night for a year. The carbon lamp consumes 112 watts or 448 kw.-hours for a year, while the tungsten lamp consumes 40 watts or 160 kw.-hours per year, or a saving of 288 kw.-hours. At 2 cents per kw.-hour, this saving is $5.76 annually. Assuming four renewals of the carbon lamp and three of the tungsten lamp per annum, the increased cost of tungsten renewals for central stations which use 1,000 to 5,000 lamps of all kinds per year will be $1.45 annually, giving a net saving, including power and lamp renewals, of $4.31 annually. If the the energy cost is 1.5 cents per kilowatt-hour the economy gained due to the substitution of the tungsten lamp will

be \$2.87. The series tungsten lamp has the additional advantage of not blackening as does the carbon series lamp in the early stages of its life. The maintenance of series tungsten lamps is also much less troublesome than that of arc lamps.

The series lamp business is increasing enormously on account of the high efficiency of the tungsten lamp. The customary practice of central stations in changing over

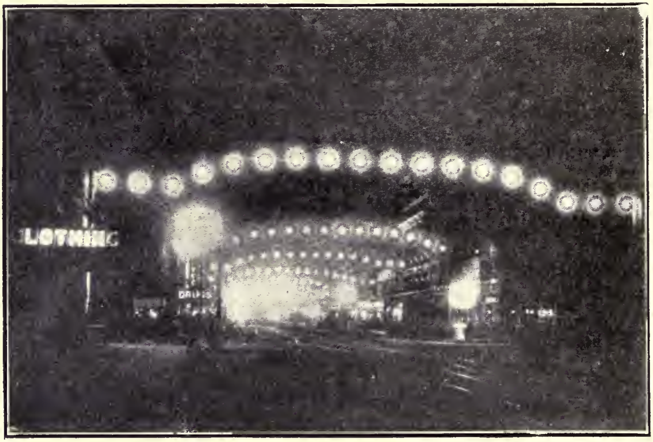


FIG. 141.—Series Tungsten Street Lighting of Span or Stringer Type.

from carbon to tungsten lamps is to give the municipality some of the benefits by changing from 25-candle-power carbon to 32-candle-power tungsten lamps.

In Fig. 141 is shown a most effective method of street illumination by means of series tungsten lamps as employed on Canal Street, Grand Rapids, Mich. The installation consists of 15 spans across the street, with 18 60-cp., 75-watt tungsten lamps in series on each span. The spans are 100 feet apart, thus illuminating nearly 1,500 linear feet of space and about 110 feet in width. The initial

expense of the installation for material and labor was practically $50 per span, or a total of $750, divided among a large number of merchants in an association, so that the individual initial expense was very small. The installation is permanent and from the standpoint of the merchants is very attractive, as it is regarded as a most conspicuous advertisement for their business. Since the installation was made it is said that the street is thronged with people every night, thus offering ample evidence of its success from an advertising view-point.

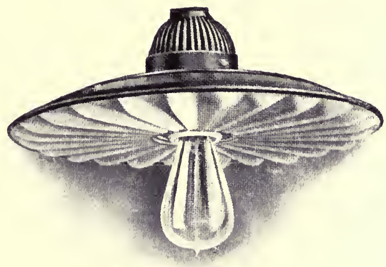


Fig. 142.—Lighting Fixture for Series Tungsten System.

The improvement of lighting fixtures for series incandescent lighting has been constant with the development of the series tungsten lamp, and one of the latest designs of reflectors for use is shown in Fig. 142. The reflector consists of an 18-in. porcelain enamelled steel reflector, fluted in order to give an effective candle-power distribution, and protected by a copper or painted steel hood attached to a cast holder. In the illustration shown malleable iron cross-arms support pony glass insulators in a vertical position, but these may be cast in one piece with the holders, so that the insulators may be held at right angles to the stem. "The radial wave" reflector, besides being fluted and slightly convex, is adjusted at such an angle with relation to the filament and of great enough diameter to intercept the light radiated in the direction of the base.

The Holophane Street Lighting Reflector is shown in Fig.

143, and was designed to accomplish the following results:

First, to do away with the bright patches of light and to distribute equally the light rays in desired directions; second, so to construct a globe or reflector that the maximum light rays will be thrown not only out toward the street, but up and down the street as well: third, to obtain

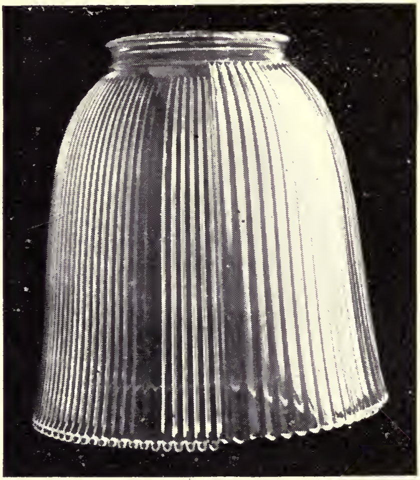


Fig. 143.—Holophane Series Tungsten Street Lighting Reflector.

this distribution by a globe or reflector which would not be affected, to any marked degree, by the elements; fourth, to protect the eye as far as possible from the high intrinsic brilliancy of our modern light sources without much loss by absorption; fifth, to obtain a globe or reflector for out-of-door use that would be tough and not easily broken and would in turn protect the lamp as much as possible. The reflector shown in Fig. 143 has two faces, or more literally speaking, a face and a back. The face, or that

portion which faces the street proper (the left half in Fig. 143), has a smooth exterior with a series of vertical reflecting and refracting prisms on the interior. The back, or that portion which is toward the sidewalk (the right half of Fig. 143), has a series of vertical totally reflecting prisms on the exterior and a smooth interior. As all prisms are vertical they do not afford an easy resting-place for dust, and rain will, to a large measure, assist in keeping it clean.

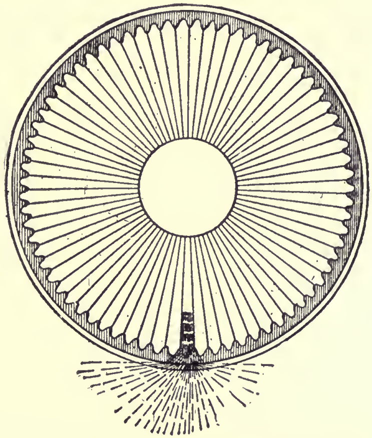


FIG. 144.—Interior of Series Tungsten Reflector.

The maximum intensity of illumination in the horizontal plane with this reflector is at 65 degrees, both sides of a zero plane perpendicular to the sidewalk, or in other words, 25 degrees out from the curb line toward the street. By directing the maximum intensity at this point, the strongest rays are thrown past such obstructions on the curb line as trees, poles, posts, etc., and by throwing the light rays 10 degrees below the horizontal the rays are spread out in such a manner that they uniformly illuminate the street proper.

A suggestion for the upper part of a fixture (pole or post) on which this reflector may be used is shown in Fig. 146, while Fig. 145 is the cross-section or detail drawing of the reflector, holder, socket, insulating joint, etc. It will be noticed that this reflector will, to a large measure, correct the general faulty appearance of the incandescent lamp

when used with the ordinary type of flat reflector on a post, inasmuch as in the latter case the small lamp appears to be altogether out of proportion in comparison with the post which supports it, and therefore destroys the symmetry or proportion of the unit as a whole. The unit as suggested by Fig. 146 gives an appearance of size which overcomes this awkwardness.

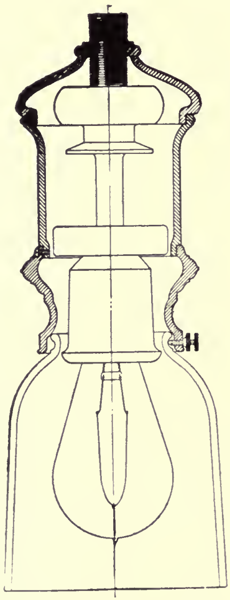


Fig. 145.—Cross Sectional View of Reflector with Characteristic Type of Series Tungsten Lamp.

The plan of suspended lights over the streets, instead of concentrated lamps on posts on the side, is coming to be regarded as the most practical and effective method of obtaining correct illuminating results. For arch lighting, which is making considerable progress, the tungsten series lamp lends itself most readily, whereas the gas arc is unsuited to any but concentrated lighting. In the tungsten arch lighting discussed above, a comparison was made on another street with gas arcs, the aggregate candle-power of which was approximately the same as that of the combined tungsten lamps. When the subject of cost was investigated it was discovered that for the number of gas arcs required to produce an illuminating effect anywhere near equal to that of the series tungsten system, the bid *for gas lighting was nearly double that for series tungsten lighting.*

In comparison with flame arcs for street illumination, as ordinarily suspended, the series tungsten arch suspen-

sion is superior in respect to distribution. The series tungsten system is also superior in point of attendance, since the flame arcs are short burning, requiring trimming every day. In point of maintenance the long life of the

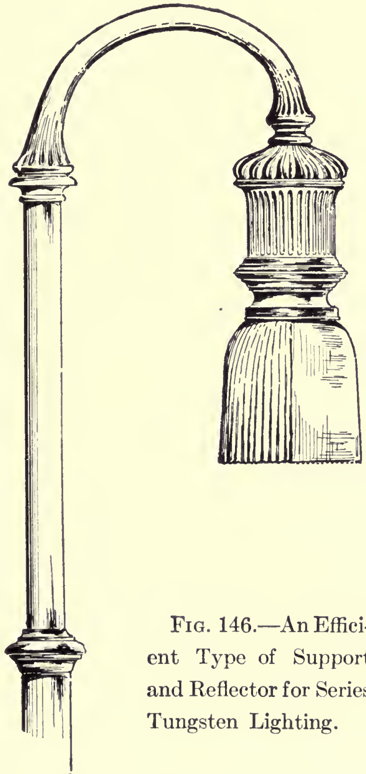


Fig. 146.—An Efficient Type of Support and Reflector for Series Tungsten Lighting.

series tungsten lamp makes the renewal expense low. The energy consumed per 100 feet of street is but a little more than one kilowatt; in the case cited (Grand Rapids arch system), the 14 lamps per arch consume 75 watts each or a total of 1,050 watts. From two to three times this

energy is hence required to operate the usual arrangement of flame arcs where the lamps are concentrated on posts.

In a paper presented by Mr. Walter C. Allen before the New York section of the Illuminating Engineering Society, January 14, 1909, a very interesting report is made of illumination surveys made by the Electrical Testing Laboratories of New York City, on certain streets of Washington, D. C., illuminated by high-efficiency lamps. These tests showed the following results:

Kind of Lamp	Cost per Foot of Street, Cents	Average Illumination, Foot-Candles	Average Variation from Mean, Per cent
Magnetite arc	27.5	0.062	106.9
Series enclosed arc (D.C.)	27.5	0.036	106.9
Graphitized carbon incan.	25.2	0.012	29.6
Tungsten series	25.2	0.013	33.0
Gas mantle	32.1	0.028	24.8

The value of the cost in each case being based on lighting per foot of street, the lamps being used 3,690 hours per year. Each arc lamp cost $85 per year; a 25-cp. carbon filament lamp, $20; a 40-candle-power tungsten lamp, $24; a 60-candle-power mantle gas lamp, $20.85. The above prices cover all costs—equipment and service.

On account of the newness of the tungsten series system of lighting, comparative data on the economy, artistic effect, life, etc., of these lamps are somewhat meagre. In Hartford, Conn., the Hartford Electric Light Company has made an experimental installation, the results from which, in the language of Mr. R. W. Rollins, general manager, are as follows: "We have installed in Pearl Street, in this city, several 250-watt tungsten lamps in a ver-

FIG. 147.—Beautiful and Efficient Illuminating Effect Produced by Series Mazda Tungsten Lamps in Central Park, New York.

tical position on iron posts, placing the lamps about 9½ feet above the sidewalk and enclosing the lamps in an opalescent outer globe. On this street, we placed two of these lamps in place of each arc light, thereby distributing the light throughout the street much more uniformly than was accomplished by the arcs. The lighting of the street is very much better than with arc lighting, being much softer and pleasanter." In *The Electrical World* of October 3, 1908, is published a series of tests made on 60-cp. tungsten series lamps installed on the lines of the Hartford Company. These tests are remarkable as showing the long life of such lamps, and their slight decrease in candle-power:

These lamps were all tested on 6.25 amperes (approximately) direct current and were compared for discoloration with the several lamps of varying progressive degrees of blackness lettered "A," "B," "C," etc., to "E"; "A" being very slightly blackened and "E" being very badly blackened. (Page 272.)

The remarkable life of tungsten series lamps is well evidenced from the following data compiled by the Bel Air (Md.) Electric Company. In January, 1908, this company installed a street series system comprising fifty 40-watt lamps, fitted with radial reflectors. A record of each lamp was kept, and also a record of the number of hours the system was in use, which averaged twelve hours per day. Of the original fifty lamps installed (Feb. 22, 1908) but thirteen burned out up to July 1, 1910. Thirty-seven have burned steadily 10,308 hours, and are still burning with no apparent diminution of light, although the glass is slightly blackened in some instances.

The table below is a record of the life of the lamp up to July 1, 1910.

1.	Burned	out	after	life	of	364	hours.	
2.	Broken		"	"	"	480	"	
3.	Burned	"	"	"	"	924	"	
4.	"	"	"	"	"	1300	"	
5.	Broken		"	"	"	2240	"	
6.	Burned	"	"	"	"	2868	"	
7.	Broken		"	"	"	3024	"	
8.	"		"	"	"	3084	"	
9.	"		"	"	"	4188	"	
10.	Burned	"	"	"	"	2520	"	(No. 5 renewal.)
11.	"	"	"	"	"	4956	"	
12.	"	"	"	"	"	4380	"	(No. 3 renewal.)
13.	"	"	by lightning after life of 5508 hours.					
14.	"	"	" " " " "			5852	"	(No. 1 renewal.)
15.	"	"	after life of 7044 hours.					(A new lamp added to system.
16.	"	"	"	"	"	3432	"	
17.	"	"	"	"	"	3840	"	(No. 9 renewal.)
18.	Broken		"	"	"	8340	"	
19.	"		"	"	"	1728	"	(No. 16 renewal.)

The cost of operating the 250-watt Mazda street series tungsten lamp for 4,000 hours' service per year is approximately \$23, divided as follows: Energy at 1.5 cents per kilowatt-hour, \$15; lamp renewals, \$7.50; trimming and labor costs \$1. In comparison with the cost of operating any series arc lamp, which figure is at least \$30 in case of the 6.6-ampere alternating current arc with 450 watts at the lamp terminals, there is considerable saving in using the Mazda lamp.

The 250-watt Mazda series tungsten operates satisfactorily on all series circuits. The lamp has a unity power factor, and shows but slight reduction in initial candle-power throughout its life. The 250-watt Mazda lamp is made for currents ranging from 4 to 8 amperes and for voltages from 62.5 to 31.2. It has a bulb five inches in diameter.

TESTS OF SERIES TUNGSTEN LAMPS TAKEN FROM WEST HARTFORD AND ELMWOOD CIRCUITS

No.	Cp.	Volts	Amp.	Watts	W.P.C.	Discoloration
12........	55.5	10.4	6.21	71.0	1.28	"A"
13........	57.0	10.9	6.23	68.0	1.19	"A"
14........	60.0	11.0	6.26	69.0	1.15	"A"
15........	57.5	10.5	6.27	66.0	1.15	"A"
16........	63.5	10.8	6.24	67.5	1.06	"A"
17........	65.5	11.0	6.23	68.5	1.04	"A"
18........	63.0	10.5	6.16	65.0	1.03	"A"
19........	73.0	10.9	6.24	68.0	.93	"A"
20........	59.0	10.7	6.21	66.5	1.13	"A"

Installed October 16, 1907. Life of lamps when tested, 3,273 hours.

No.	Cp.	Volts	Amp.	Watts	W.P.C.	Discoloration
1........	52.0	10.1	6.26	64.0	1.23	"A"
2........	24.2	7.0	6.23	43.5	1.08	"A"
3........	57.0	10.3	6.29	65.0	1.14	"A"
4........	59.0	10.7	6.23	66.5	1.13	"A"
5........	60.0	10.5	6.26	66.0	1.10	"A"
6........	52.5	10.0	6.24	62.5	1.19	"A"
7........	66.0	10.4	6.25	65.0	.98	"A"
8........	72.0	11.6	6.25	72.5	1.00	"A"
9........	59.0	10.3	6.24	64.0	1.08	"A"
10........	51.5	10.1	6.26	63.0	1.22	"A"
11........	61.5	10.9	6.27	68.4	1.11	"A"
12........	69.0	10.3	6.25	64.5	.93	"A"

Installed October 15, 1907. Life of lamps when tested, 3,273 hours.

INDEX

Arc Lamps, 114
Adams-Bagnall regenerative flaming arc, 137–141
Advantages and disadvantages of flaming arc lamps, 124
Advertising features of flaming arc lamps, 125
Beck flaming arc lamp, 135, 136
Comparison of economy of regenerative flaming arc over ordinary enclosed arcs, 141, 142, 143
Comparison of operating costs of ordinary enclosed arcs and flaming arcs, 127–131
Early types of Bremer, 115
Efficiency and illuminating characteristics of flaming arc lamps, 121
Excello flaming arc, 133, 134, 135
Factors influencing economy of flaming arc lamps, 123
Flaming or luminous, 114
Functions of "Economizer" and "Blow-Magnet," 115, 116
General Electric flaming arc, 131, 132
Influence of flaming arc in compelling use of tungsten lamp, 126
Influence of globe on light-distribution of flaming arc lamps, 122
Jandus "regenerative" flaming arc lamp, 136, 137
Kinds of flaming and how produced, 116, 117
Lamps comprising luminous group, 114
Limitations of dimensions of flaming arc carbons, 118
Limiting percentages of metallic salts in, 117
Maintenance expense of flaming arcs, 127
Mechanical construction of flaming arc lamps, 118
Multi-carbon and magazine flaming arc lamps, 145, 146
Operation of clock-type flaming arc mechanism, 120
Operation of clutch-type of flaming arc, 119
Operation of clutch-type flaming arc mechanism, 120
Operation of gravity-feed arc lamps, 119
Operation of hot-wire type flaming arc mechanism, 120
Operation of motor-type flaming arc mechanism, 120
Outdoor lighting by flaming arc lamp in Germany, 124, 125
Present-day field of service of flaming arc lamp, 124
Vertical electrode flaming arc lamps, 146–148

Bolton, Dr. Werner von, 87

CANDLE-POWER, unit of, 13
Foot-candle, definition of, 14
Lumen-candle, definition of, 13
Meter-candle, definition of, 14
Watts per candle, 14
Color, various values of different sources of light, 4–7
Colorimeter, measurements of various sources, 5
Table of colorimeter readings on light-sources, 6
Table of colors of commercial illuminants, 5

EFFICIENCY of light-distribution, 15
Of light-source, 15
Of visual perception, 15

FIXTURES, practical design of lighting, 242–244

HELION lamp, 100, 101, 102

ILLUMINANTS, definition of efficiency of electric, 14
Economy of—definition, 15
Illumination, advantages of large light-emission surfaces for, 202, 203
Art of modern—definition of, 190–192
Cost of inefficient versus efficient installations, 200, 201
Defections of present-day, 189
Degree to which reflectors reach in efficiency, 194
Effect of ceiling and wall color on, 197, 198, 199
Foot-candles needed for various classes of interiors, 247
Fundamental principles of indirect, 212–216
Haphazard methods of illumination, 195, 196
Methods of diffusing light from high-candle-power sources, 201
Need of more careful attention to details, 197
Of school-houses, 216–223
Physiological laws of, 191
Points to be observed in efficient, 192
Preliminary calculation of, 244–247
Principles of efficient and economical interior, 188
Proper definition of efficiency of, 193
Proper design of office, 206, 207, 208
Proper ratio of light directed upward and downward, 193, 194
Relation of, to physics and physiology, 188
Show-window, 209–212
Simple method of calculating for various interiors, 246–247
Tables of watts per square foot for various lamps, 245–246

LIGHT, origin of, 1
Phenomenon of reflection and absorption, 2
Table of per cents reflected from surfaces, 2

MAGNETITE Arc Lamp, appearance of arc and crater, 149
Characteristics of, 148
Composition of electrodes of, 149
Disadvantages of, 150, 158
General Electric magnetite arc, 155–156
Illuminating value and distribution, 150
Illumination and color of magnetite arc, 157
Invention of, 148
Kinds of circuits principally adapted for, 158
Steinmetz ventilated magnetic arc, 151, 152
Table of cost of operation of luminous and other arc lamps, 160
Table of luminometer values of luminous and other arcs, 160
Uses of, in street lighting, 158
Mechanism of the eye, 2–4
Metallic-filament and electrolytic incandescent lamps, 16
Initial invention of metallic-filament lamp, 19
Proper installation and shading of, 61, 62, 63
Retrospect and introspect of, 17–18
Moore Tube Lamp, construction of, 179, 180
Degree of vacuum required in, 182, 183
Disadvantages of, 185–187
Field of service principally adapted for, 187
Functions of feeder-valve of, 180, 181
How installed, 183, 184
Illuminating value and energy consumption, 184, 185
Invention of, 179

OSMIUM Lamp, 97

PHOTOMETERS, Bunsen, 10
Illuminometers, 8
Kinds of, 10
Lummer-Brodhun, 10
Photometry, definition of, 8
Obstacles to accuracy in, 12
Simple photometry, 8
Spectro-photometry, 8
"Yellow spot" effect, 13

Reflectors, 203
Care, cleaning, and maintenance of prismatic, 238–242
Effect of changing position of, 206
Extensive, intensive, and focussing, 224–226
Forms of, for incandescent lamps, 204, 205
General Electric diffusing, 237, 238
Gillinder type of prismatic, 236
Holophane arcs, data for proper use, 229–231
Holophane high-efficiency, 223
Holophane reflector bowls, 232–235
Holophane spheres and hemispheres, 226–229
Illuminating data for Holophane prismatic, 235, 236
Importance of using tested, 205
Kinds of, for show-windows, 209–212
Mill type, 238
Resistance, rise and fall of, in carbon and tungsten filaments, 41

Street Illumination, advantages of arch system, 259
Advantages of lamp-post systems, 259
Arch system at Grand Rapids, Mich., 258, 262
Disadvantages of arch system, 259
Economy of street series-tungsten lamps, 261
Effect from raising street arcs above usual height, 252, 253
Effect of giving undue importance to small candle-power units, 248–250
Effective design of post for series-tungsten system, 265–268
Experience of Bel Air (Md.) Co. with series-tungsten lamps, 270
Fallacies in design of, 248–253
Holophane street-lighting reflector, 264, 265
Lamp-posts versus street arches, 258
Lighting fixtures for street series-tungsten lamps, 263
Methods of ornamental curb line, 253–258
Series-tungsten system of, 260
Tables of comparative data on operating costs, 268, 271
Tables showing life of series-tungsten street lamps, 272
Type of lamp-post used in Denver, Colo., 255, 256
Type of lamp-post used in Des Moines, Iowa, 253
Type of lamp-post used in Minneapolis, 256
Type of lamp-post used in Superior, Wis., 254
Wattages of Mazda series-tungsten lamps, 260, 261

Tantalum Lamp, behavior of, in service, 93, 94, 95, 96
Chemical, physical, and electrical properties of, 87

TANTALUM Lamp, current-consumption of, 92
Early difficulties in manufacture of, 88, 89, 90
Invention of, 87
Present types of, 91, 92
Useful life of, 93
Titanium-Carbide Arc Lamp, 160
Titanium Lamp, 102
Tungsten, ores from which obtained, 21
Output of different countries, and value, 22
Physical and electrical properties of, 23
Tungsten Filaments, American process of making, 24
British Westinghouse method of connection, 37
Connections of leading-in wires, 37
General Electric process, 26
Just-Hanaman process, 24
Kuzel's method of connection, 38
Kuzel process, 25
Lux process, 27
Recent Bolton process, 29
Siemens & Halske process, 28
Support of, 31–32, 33, 34
Westinghouse "wire type," 34, 35, 36
"Z" process, 28
Tungsten Lamps, Allgemeine Elektricitäts Gesellschaft's method, 39
British Thomson-Houston method, 39
Higher initial brilliancy of tungsten lamps, 48, 49
Kuzel's method of increasing specific resistance, 38, 39
Methods of increasing specific resistance of, 38
Radiating power of, 40
Tables of cost of producing light with high-efficiency lamps, 44, 47
Temperature of, 40
Three-voltage rating of "Mazda," 41, 42
Treatment of, to prevent blackening, 38
Useful life of, 40
Values of resistance of, 40–41
Voltage variation, effect of, on life, 50, 51, 52
Analyses of cost of operation of tungsten and carbon lamps, 71, 72, 73
Commercial effect of introduction of, 73, 74, 75
Construction of, 162
Devices to absorb shocks in, 68, 69, 70, 71
Difficulties in manufacture of "high-voltage," 55, 56, 57, 58, 59, 60

Tungsten Lamps, economy of "Dunham method" of light-charges for, 86
Electrical characteristics of, 164
Electrodes for, 162
Energy consumption and illuminating characteristics of, 161
Factors which have retarded rapid introduction of, 75–80
Low-voltage lamps, conditions of service, 63, 64, 65
Meter-basis schedule of charges of Chicago Edison Co., 85, 86
Operating-costs of, 164
Policies of prominent central stations with respect to, 80
Policy of Commonwealth Edison Co. of Chicago, 81
Policy of Edison Company of New York, 82, 83
Policy of Edison Electrical Illuminating Co. of Boston, Mass., 80, 81
Policy of Edison Electrical Illuminating Co. of Brooklyn, N. Y., 82
Policy of Hartford Electric Light Co., Hartford, Conn., 83, 84
Shortcomings of, 164, 165
Transformer types for low-voltage lamps, 66, 67, 68

Uviol Lamps, 178
Uses of, in industrial work, 178
Uses of, in medical practice, 178

Vapor Lamps, 166
Color and commercial uses of Cooper-Hewitt lamps, 172–174
Color value of quartz lamp, 176
Characteristics of Cooper-Hewitt lamps, 168, 169, 170
Construction of Cooper-Hewitt lamps, 166, 167, 168
Construction of quartz lamps, 174, 175
Consumption of commercial quartz lamps, 177, 178
Efficiency of quartz lamps, 175
Insect-destroying features of quartz lamps, 178
Invention of, 166
Küch quartz lamp—construction of, 176, 177
Life of quartz lamps, 175
Methods of connection and starting of Cooper-Hewitt lamps, 172–174
Quartz mercury-vapor lamp, 174
Uses of quartz lamp, 174

CIVIL ENGINEERING—*Continued*

5E Highways; Municipal Engineering; Sanitary Engineering; Water Supply. **Forestry. Horticulture, Botany and Landscape Gardening.**

6—Design. Decoration. Drawing: General; Descriptive Geometry; Kinematics; Mechanical.

ELECTRICAL ENGINEERING—PHYSICS

7—General and Unclassified; Batteries; Central Station Practice; Distribution and Transmission; Dynamo-Electro Machinery; Electro-Chemistry and Metallurgy; Measuring Instruments and Miscellaneous Apparatus.

8—Astronomy. Meteorology. Explosives. Marine and Naval Engineering. Military. Miscellaneous Books.

MATHEMATICS

9—General; Algebra; Analytic and Plane Geometry; Calculus; Trigonometry; Vector Analysis.

MECHANICAL ENGINEERING

10A General and Unclassified; Foundry Practice; Shop Practice.

10B Gas Power and Internal Combustion Engines; Heating and Ventilation; Refrigeration.

10C Machine Design and Mechanism; Power Transmission; Steam Power and Power Plants; Thermodynamics and Heat Power.

11—Mechanics.

12—Medicine. Pharmacy. Medical and Pharmaceutical Chemistry. Sanitary Science and Engineering. Bacteriology and Biology.

MINING ENGINEERING

13—General; Assaying; Excavation, Earthwork, Tunneling, Etc.; Explosives; Geology; Metallurgy; Mineralogy; Prospecting; Ventilation.